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Fuel-Efficient Sewage Sludge Incineration

Camp, Dresser and McKee, Inc., Boston, MA

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FUEL-EFFICIENT SEWAGE SLUDGE INCINERATION

by

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Contract No. 68-03-3346

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16. ABSTRACT

A study was performed to evaluate the status of incineration with low fuel use as a sludge disposal technology. The energy requirements, life-cycle costs, operation and maintenance requirements, and process capabilities of four sludge incineration facilities were evaluated. These facilities used a range of sludge thickening, conditioning, dewatering, and incineration technologies.

The results provided realistic cost and energy requirements for a fuel-efficient sludge incineration facility and highlighted operational, managerial, and design features that contributed to the fuel efficiency of the incineration process. This information provides a basis for evaluating both the applicability of sludge incineration in future facilities and the cost and energy efficiency of existing incineration facilities.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authorizitative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This project was undertaken to document realistic cost and energy requirements for a fuel-efficient sludge incineration facility and to highlight operational, managerial, and design features that contribute to the fuel-efficiency of the incineration process. The information herein was based on plant site visits, available literature, and design and operation experience.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

The purpose of this report is to evaluate the status of incineration with low fuel use as a sludge disposal technology. Four sludge incineration facilities are evaluated with regards to energy requirements, life-cycle costs, operation and maintenance requirements, and process capabilities. The four facilities represent a range of sludge thickening, conditioning, dewatering, and incineration technologies.

This report provides the reader with a summary of realistic cost and energy requirements for a well-operated, fuel-efficient sludge incineration facility and highlights operational, managerial, and design features that contribute to the fuel efficiency of the incineration process. This information provides the reader with a basis to evaluate both the applicability of incineration as a sludge processing alternative for future facilities and the cost and energy efficiency of existing incineration facilities. This information is useful to regulatory personnel and design engineers who are evaluating sludge disposal technologies for new or upgraded facilities and to operators of existing facilities who are attempting to make their operation more cost and energy effective. This project covers a period from July 1987 to September 1989.

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SECTION 1
INTRODUCTION

REPORT OBJECTIVES

The purpose of this report is to evaluate the status of incineration with low fuel use as a sludge disposal technology. Four sludge incineration facilities are evaluated with regards to energy requirements, life-cycle costs, operation and maintenance requirements, and process capabilities.

This report provides realistic cost and energy requirements for a fuel-efficient sludge incineration facility and highlights operational, managerial, and design features that contribute to the fuel efficiency of the incineration process. This information provides a basis for evaluating both the applicability of sludge incineration and the cost and energy efficiency of existing incineration facilities. This information is useful to regulatory personnel and design engineers who are evaluating sludge disposal technologies for new or upgraded facilities and to operators of existing facilities who are attempting to make their operation more cost and energy efficient.

BACKGROUND

Sludge handling and disposal has become the major operational concern at a great many wastewater treatment facilities for several reasons:

- Sludge production has increased as effluent standards have become more stringent and treatment facilities have provided a higher level of treatment.
- Public concern regarding odors, increased traffic, and noticeable air emissions has increased.

- Sludge disposal has become increasingly difficult because of concerns about pathogens, toxic organics, and metals, and because of increased difficulty is siting residual disposal areas.

- Sludge disposal has become very costly. An evaluation of four major secondary facilities in the greater Toronto area showed that between 50 and 60 percent of each facility's total operation and maintenance budget is dedicated to solids handling and disposal (1).

For these reasons, developing improved means of sludge handling and disposal has become a top priority within the wastewater industry. This report will evaluate the status of one sludge disposal technology; sludge incineration with low fuel use.

Because of its simplicity and relatively low cost, municipal sludge incineration was a popular sludge processing alternative until the mid 1970s. Dramatic increases in the price of fossil fuel coupled with increased sensitivity to air pollution problems from incinerator emissions made sludge incineration less attractive. Also, secondary wastewater treatment, which was implemented at many facilities, resulted in more sludge, and sludge that was more difficult to dewater. Incineration, therefore, became more costly to incinerate. Other problems that hampered fuel-efficient incineration then, and still continue to hamper fuel efficiency, include (2):

- Sludge cake not dry enough for autogenous combustion.
- Mechanical problems with equipment.
- Variations in quantity and quality of the sludge resulting in system upsets.
- Problems handling slag, clinkers, screenings, grit, and scum.
- Difficulties operating incinerators that were oversized in design.

- Inability to monitor key process operational parameters.
- Operator training which is absent, incomplete, or not updated.
- Emission standards not being met.
- Odor problems and visible emissions.
- Corrosion and plugging problems associated with heat recovery equipment.
- Lack of coordination in the design of the individual unit processes in the solids train.
- Lack of coordination between dewatering operators and incinerator operators.
- Difficulty in maintaining uniform operation conditions that minimize pollutant formation and emissions.

Because of these factors, many incineration facilities were mothballed in favor of more cost effective or less problematic sludge handling alternatives.

Today, many factors are creating a renewed interest in sludge incineration. Some of the advantages that are again making sludge incineration attractive include:

- Volume Reduction
  In many areas, the scarcity of available land has made siting a landfill large enough to provide for 20 years of sludge disposal impossible. Incineration reduces the volume and weight of wet sludge by over 95 percent (mass reduction on a dry weight basis of 40 to 75 percent), thus reducing the amount of area required for residual disposal to a minimum.

- Energy Recovery
  In recent years, many advances have been made in the ability to recover heat from the incineration process and reuse the energy throughout the plant. This has significantly increased the cost effectiveness of the incineration process.

- Sludge Thickening/Dewatering
  Recent improvements in sludge thickening and dewatering technology have made it possible to obtain a relatively dry cake from primary/waste activated sludge mixtures. This reduces the auxiliary fuel requirements of the incineration process, making incineration more cost effective.

- Emission Control
  Improvements in emission control technology have made it possible to meet existing emission standards on a consistent basis.

A 1988 EPA survey of publicly owned treatment works (POTWs) demonstrates the importance of the incineration process in municipal sludge disposal. Approximately 21 percent of the sludge produced at the 15,305 facilities included in the survey was incinerated (3). In the future, some of the facilities that now landfill or land apply their sludge will be forced to seek alternative disposal methods because available undeveloped land is scarce and more stringent land application regulations might be implemented. Facilities that ocean dump sludge are currently being forced to seek alternate disposal methods. Many of these facilities will evaluate incineration as one of the solids handling alternatives.

This report and the appended case-study reports provide a basis for evaluating the role of sludge incineration in meeting these future needs.

PROJECT METHODOLOGY

The project was performed in three phases. Phase I and Phase II of the project were completed in September 1988.

Phase I - Identify and gather information on operating facilities

The purpose of Phase I was to identify 15 to 20 fuel-efficient incineration facilities operating in North America. To identify these facilities, several manufacturers, consultants, and EPA personnel working in the field of sludge incineration were contacted. These contacts yielded a list of 49 possible fuel-efficient incineration facilities (see Table 1). To verify the information provided by these contacts and have a basis for narrowing this list down to 15 to 20 facilities suitable for further study, these 49 facilities were telephoned and asked to provide general information such as operational status, fuel consumption, heat recovery capability, and willingness to provide more detailed operations data. Out of the 49 facilities contacted, we found 20 facilities that might be self-sustaining or fuel efficient. These facilities were then arranged by furnace types and sludge conditioning methods, as presented in Table 2.

Phase II - Select properly operated facilities for in-depth performance evaluation

The purpose of Phase II was to select three or four facilities that would be suitable for an in-depth performance evaluation to be completed in Phase III. To be considered a good candidate for an in-depth performance evaluation, the following characteristics were desirable:

- low auxiliary fuel consumption by the incineration system
- a knowledgeable operations and maintenance staff
- a facility on-line long enough to have optimized the incineration process and developed a reasonable backlog of operations and maintenance data
- no major design flaws
- generally good operations record in areas other than auxiliary fuel consumption (i.e. air emissions, sludge dewatering, odor control, etc.)

- at least one facility should have received grant funding under the EPA Innovative Alternative (I/A) Technology Grant Program

Based on these criteria, the list of 20 facilities developed in Phase I was screened down to the following seven facilities:

1. Upper Blackstone WPCF, Worcester, MA
2. San Mateo WPCF, San Mateo, CA
3. Indianapolis WPCF, Indianapolis, IN
4. Metro WPCF, Minneapolis, MN
5. Duffin Creek WPCF, Toronto, Canada
6. Lakeview WPCF, Toronto, Canada
7. Cranston WPCF, Cranston, RI

Only one of these seven facilities, the Cranston WPCF, received grant funding under the EPA Innovative Alternative (I/A) Technology Grant Program.

Each of these seven facilities was visited to collect additional information and to assess first-hand if the facility would be a good candidate for further study.

Based on the criteria presented previously, four facilities were selected for Phase III study. The name, location, and technology utilized at each of these four facilities is listed below.

1. Upper Blackstone WPCF, Worcester, MA
    Polymer chemical conditioning
    Belt filter press dewatering
    Multiple-hearth incineration.

2. Metro WPCF, Minneapolis, MN
    Thermal sludge conditioning
    Polymer chemical conditioning
    Roll press dewatering
    Multiple-hearth incineration

TABLE 1

LIST OF POSSIBLE FUEL-EFFICIENT INCINERATION FACILITIES

Location (by state)	Plant Name
Multiple Hearth Incinerators	
Walnut Creek, CA	Central Contra Costa Sanitary District
San Mateo, CA	San Mateo STP
Hartford, CT	Hartford STP
Naugatuck, CT	Naugatuck Treatment Co.
Waterbury, CT	Waterbury STP
Indianapolis, IN	Indianapolis STP
Cedar Rapids, IA	Cedar Rapids STP
Worcester, MA	Upper Blackstone STP
Kalamazoo, MI	Kalamazoo STP
St. Paul, MN	Metropolitan STP
Kansas City, MO	Blue River STP
St. Louis, MO	Lemay Plant
Concord, NC	Rock River Regional WWTF
Greensboro, NC	N. Buffalo WWTF
Princeton, NJ	Stony Brook Regional WWTF
Wayne, NJ	Mt View STP
Rochester, NY	Frank E. Van Lare WPCF
Akron, OH	Akron WPCF
Warren, OH	Warren STP
Toronto, Ontario	Ashbridges Bay STP
Chester, PA	Delora-Chester WPCF
Colmar, PA	Hartfield Township STP
Cranston, RI	Cranston WPCF
Nashville, TN	Nashville Central WPCF
Arlington, VA	Arlington Central WPCF
Charlottesville, VA	Rivanna Water and Sewer Authority
Green Bay, WI	Green Bay STP

TABLE 1
(continued)

LIST OF POSSIBLE FUEL-EFFICIENT INCINERATION FACILITIES

Location (by state)	Plant Name
Fluidized Bed Incinerators	
Redwood City, CA	S. Bayside WPCF
Lake Tahoe, CA	South Lake Tahoe STP
Kansas City, KS	Kaw Point Plant
Kansas City, KS	Kansas City Plant No. 20
Lynn, MA	Lynn Regional WPCF
Duluth, MN	Western Lake Superior Sewerage District
Lincoln Park, NJ	Two Bridges STP
North Bergen, NJ	North Bergen STP
Raritan, NJ	Somerset-Raritan WPCF
Union Beach, NJ	Bayshore Regional WPCF
Port Washington, NY	Port Washington STP
Mechanicville, NY	Saratoga County Sewerage District
Southampton, NY	Southampton STP
Utica, NY	Oneida County WPCF
Toronto, Ontario	Lakeview STP
Toronto, Ontario	Duffin Creek WPCF
King of of Prussia, PA	Matsunk STP (Trout Run)
North Charleston, SC	North Charleston STP
Electric Infrared Incinerators	
Decatur, GA	Snapfinger Creek STP
Gainesville, GA	Flat Creek STP
Fayetteville, NC	Fayetteville STP
Plano, TX	Rowlett Creek STP

TABLE 2

FUEL EFFICIENT INCINERATION FACILITIES

Sludge Conditioning/ Dewatering Method	Multiple Hearth Installations	Fluidized Bed Installations	Electric Infrared Installations
Zimpro Thermal Sludge Conditioning	Metropolitan STP, MN Green Bay STP, WI San Mateo STP, CA Ashbridges Bay STP, Ontario	Lakeview STP, Ontario	
Belt Filter Press Dewatering	Indianapolis STP, IN Upper Blackstone STP, MA Delora-Chester WPCF, PA Blue River STP, MO N. Buffalo WWTF, NC	North Bergen STP, NJ Saratoga County Severage District, NY Oneida County WPCF, NY Somerset-Raritan WPCF, NJ Bayshore Regional WPCF, NJ	
Filter Press Dewatering	Cranston WPCF, RI Rock River Regional WWTF, NC	Duffin Creek WPCF, Ontario South Bayside WPCF, CA	Flat Creek STP, GA

3. Duffin Creek WPCF, Toronto, Canada
   - Polymer chemical conditioning
   - Filter press dewatering
   - Fluidized-bed incineration

4. Cranston WPCF, Cranston, RI
   - Lime and ferric chloride chemical conditioning
   - Filter press dewatering
   - Multiple-hearth incineration

Phase III - Complete in-depth performance evaluations at four fuel-efficient facilities

Each of the four facilities selected for Phase III study was visited a second time for a two-day to three-day period to obtain plant records and detailed information regarding operation and maintenance costs and requirements, capital costs, and energy requirements for the incineration system. The incineration system was taken to be the entire solids train, including sludge thickening, chemical conditioning or thermal sludge conditioning and sidestream treatment, sludge dewatering, sludge incineration, air emissions control equipment, energy recovery equipment, and ash disposal. A detailed case-study report that summarized and evaluated this information was prepared for each of the four facilities. Each case-study report included:

- A summary of the net energy energy requirements of the individual system components (sludge thickening, dewatering, incineration, etc.) and of the system as a whole.

- A summary of operation and maintenance costs (labor, energy, consumables, materials) for each unit process and the system as a whole.

- A summary of capital costs for each unit process and the system as a whole.

- A discussion of operational, managerial, and design features that contribute to the facility's fuel efficiency.

The four case-study reports provide the data base for this report and are included in the Appendix.

SECTION 2

CONCLUSIONS

The results of this study are summarized in this section. Design and operation and maintenance practices which contribute to the energy efficiency of the incineration process are discussed, and estimates of capital costs, operation and maintenance costs, and energy consumption for a fuel-efficient sludge incineration system are presented. Each of these subjects are discussed in detail in subsequent report sections.

It should be noted that the estimates of cost and energy consumption that are presented in this study reflect plant operation under current emission control regulations. Changes in these regulations could significantly impact the cost and energy efficiency of the incineration process. Exhaust gas temperatures for the three multiple-hearth furnaces considered in this study range from 900°F (480°C) to 1100°F (590°C). None of the three multiple-hearth systems employs afterburning of the furnace exhaust gas stream, although two of these three installations have an afterburner chamber incorporated into the incineration system. Each of these facilities employees a venturi wet scrubbing system. If new air emission regulations require operation of an afterburner for all multiple-hearth systems, cost and energy requirements for multiple-hearth incineration will increase significantly. Requirements for more sophisticated emissions control technologies will increase the capital, labor, and power costs for sludge incineration. This potential for future increases in cost and energy consumption should be considered when applying the figures presented in this study.

KEYS TO SUCCESS

Although each facility visited as part of this study had several unique features which contributed to the success of the facility, there were some common operational and management features that operators at each facility agreed were essential to a fuel-efficient sludge incineration system. These features are discussed here.

Sludge Equalization

A uniform sludge flow to the incineration system is essential, both in term of quantity and quality. Each time the quality or quantity of the furnace feed changes, optimum burn conditions within the furnace change and the operator must adjust the excess air level, rabble arm rotation speed, auxiliary fuel use, or some other operational variable to maintain complete combustion conditions. If the sludge feed is kept uniform, the operator does not have to make major adjustments to the furnace and can instead concentrate on fine tuning the incineration system.

To create a uniform furnace feed, some sludge storage and mixing should be provided within the solids train. The sludge mixing will create a homogeneous sludge stream and avoid changes in sludge characteristics such as solids and volatiles content. Sludge storage will provide some buffer in the system to protect the furnace from day-to-day fluctuations in sludge production and allow changes in the furnace feed rate to be made gradually. Sludge storage also allows the incineration system to be taken off-line for regular maintenance and equipment calibration.

Staff Motivation/Training

The real key to any successful sludge incineration facility is in the plant operations and maintenance staff. An incineration system is a relatively complex system to operate and maintain. The operations staff must understand the effect that changes in excess air level, rabble arm speed, and other operational variables have on the combustion process, and the effect that the performance of the preceding solids handling processes on the furnace's operation. The maintenance staff must have the manpower and skill to provide regular maintenance on a variety of equipment. The development of a good operations and maintenance staff starts with plant management. Management must create a positive working environment that motivates the plant staff. Some of the key points to developing such an environment are:

- Staff Communication

Communication between the operators of each solids handling process is essential. Operators must understand how the performance of each unit process directly effects the performance of subsequent unit processes and recognize the importance of communicating information regarding changing sludge conditions to other operators. Management can encourage this by implementing programs such as a rotating employee program or by forming problem solving committees comprising of engineers, operators and maintenance personnel from throughout the solids handling facility.

- Staff Training

Management should encourage the plant staff to pursue advanced levels of training through in-house programs, operator certification programs, graduate level engineering programs, and activity in professional organizations and societies. This has a very positive impact on the attitude of the staff. It increases the staff's knowledge, encourages the exchange of ideas with other people within the industry, and creates a sense of staff pride regarding their facility. A knowledgeable plant staff is better able to optimize the operation of the solids train and identify new ways to improve the efficiency of the system through process modifications.

Maintenance Program

A strong maintenance program is a key component of any successful sludge incineration operation. A strong maintenance program increases the cost-effectiveness and energy efficiency of the incineration process by:

- Reducing auxiliary fuel use by minimizing unscheduled maintenance shutdowns.

- Minimizing costs for replacement materials by extending the useful life of furnace components such as the refractory brickwork and other ancillary equipment.

- Providing the operators with the information necessary to operate the incinerators fuel-efficiently by keeping the instrumentation and monitoring equipment operable and up-to-date in terms of current technology. This insures that the operators receive the information required to operate the furnace in an energy-efficient manner.

Management must provide the plant staff with an adequate budget to operate and maintain the solids handling facility. If budget allowances do not allow for regular equipment maintenance, equipment falls into a state of disrepair and, eventually, will require major repair or replacement. Over the life of a facility, it is more economical to pay the annual cost of proper preventive maintenance than to reduce annual maintenance costs to a minimum and pay for major repairs on a periodic basis.

ECONOMIC EVALUATION SUMMARY

Based on the evaluation presented in Section 4, the following ranges represent a reasonable estimate of capital and operation and maintenance costs for a well-operated sludge incineration system operating at capacity, including furnaces, heat recovery system, air pollution control system, and ash disposal system.

Annual Operation & Maintenance Costs	$ 70 to $ 90/dry ton ($77 to $99/dry tonne)
Amortized System Capital Costs	$100 to $125/dry ton ($110 to $138/dry tonne)
Total Annual Costs	$170 to $215/dry ton ($187 to $237/dry tonne)

The following ranges represent a reasonable estimate of capital and operation and maintenance costs for a complete, well-operated incineration solids train operating at capacity, including thickening and dewatering.

Annual Operation & Maintenance Costs	$180 to $200/dry ton	($198 to $200/dry tonne)
Amortized System Capital Costs	$200 to $230/ton	($220 to $253/dry tonne)
Total Annual Costs	$380 to $430/dry ton	($418 to $473/dry tonne)

All costs are presented on the basis of dewatered sludge cake.

It is important to recognize the limits of these costs estimates. Estimates of capital costs are presented on the basis of dollars per ton of installed capacity, allowing for a reasonable amount of reserve capacity. It must be recognized that capital costs can vary significantly due to site-specific factors such as subsurface conditions, local materials costs, size constraints, construction market conditions, and the amount of redundancy built into the system. These factors make it difficult to generalize about capital costs, therefore the capital cost figures presented here should be applied carefully.

Estimates of operation and maintenance costs are based upon operation at system capacity. System O&M costs can vary significantly over the life of a facility. Many unit processes require essentially the same operator attention, the same maintenance attention, and the same power consumption whether the process is lightly loaded or loaded to capacity. As a result, operation and maintenance of these unit processes is much more cost effective on a dollar per ton basis when the system is operating at design capacity.

The degree to which operation and maintenance costs for a particular facility may vary over the life of the facility depends upon the difference between initial and design year sludge quantities, the use of multiple units rather than one large unit in equipment selection, and other design factors. A system that operates at a fairly constant sludge feed throughout its design life will see little change in per ton operation and maintenance costs. A system that is sized for a design year loading that is substantially greater than initial loading conditions will likely experience a significant change in per ton operation and maintenance costs over the system's design life.

Figure 1 shows the relationship between the unit costs and the fraction of capacity in use. The curves and points are plotted for operation and maintenance only and for operation and maintenance plus amortized capital costs, for incineration only and for the total system. Because the Duffin Creek solids train was evaluated for two system capacities (one for digestion and dewatering and one for incineration), total system costs for Duffin Creek could not be included in this curve.

Actual per ton operation and maintenance costs for sludge incineration at the four subject facilities ranged from 6 percent to 186 percent greater than the per ton costs estimated for operation at capacity. The fluctuation in per ton costs over the design life of an incineration system should be considered when using the figures presented in this study.

ENERGY EVALUATION SUMMARY

Energy efficiency can be examined on several levels:

o Level A - Compare the facilities on the basis of auxiliary fuel consumed within the furnaces only.

o Level B - Same as Level A, except consider energy inputs to the heat/auxiliary boiler equipment, the emission control equipment, and the ash disposal system. Steam produced and utilized outside of the incineration system is considered an energy output.

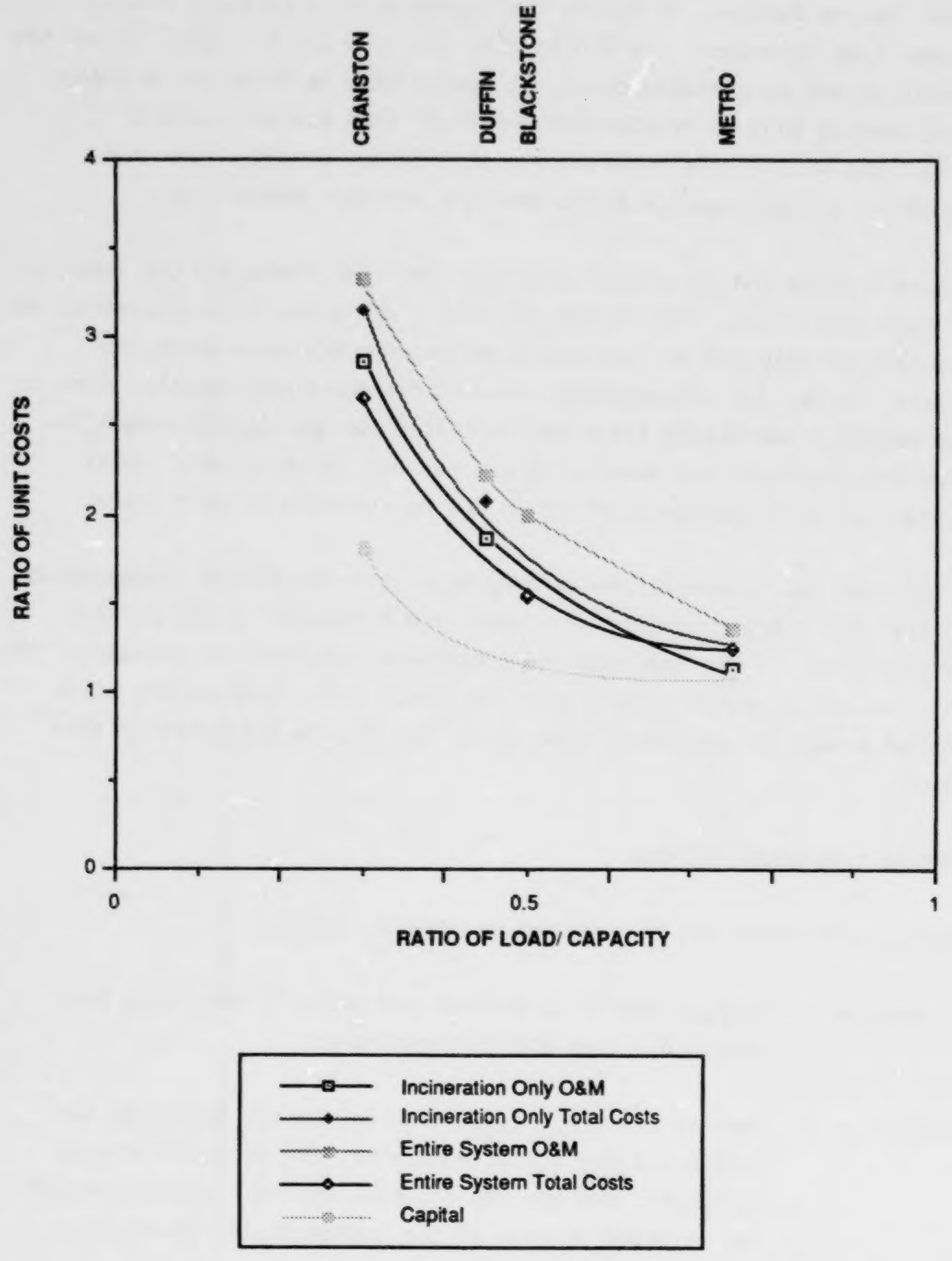


FIGURE 1
EFFECT OF LOAD ON UNIT COSTS

o Level C - Same as Level B, except that electricity for equipment is considered an energy input.

o Level D - Same as Level C, except include energy inputs to the sludge conditioning/dewatering system.

o Level E - Same as Level D, except include energy to the entire solids handling train. Auxiliary fuel, electricity for equipment, and electricity for general building requirements are considered energy inputs.

Figure 2 shows the results for the five levels of analysis.

The following generalizations can be made regarding the energy consumption of a well-operated sludge incineration facility:

- Annual auxiliary fuel consumption within the furnace itself should be in the range of 7 to 9 gallons of fuel per dry ton (29 to 38 liters/tonne) of sludge cake processed (Level A).

- If a waste heat recovery system is included in the incineration system, the incineration system can be a net energy producer if only auxiliary fuel (no electricity) is considered an energy input to the system (Level B).

- If both auxiliary fuel and electricity are considered energy inputs to the incineration system, an incineration system with a waste heat recovery system may still be a net energy producer if operating at maximum efficiency (Level C). Under these conditions, the Metro and Duffin facilities approach the goal of being a net producer at their current loading rates. It is possible that, if these facilities approach the goal of being a net producer at their current loading rates. It is possible that, if these facilities were operating at capacity, the increase in energy efficiency that results from complete equipment utilization may make the Duffin and Metro facilities net energy producers under these conditions.

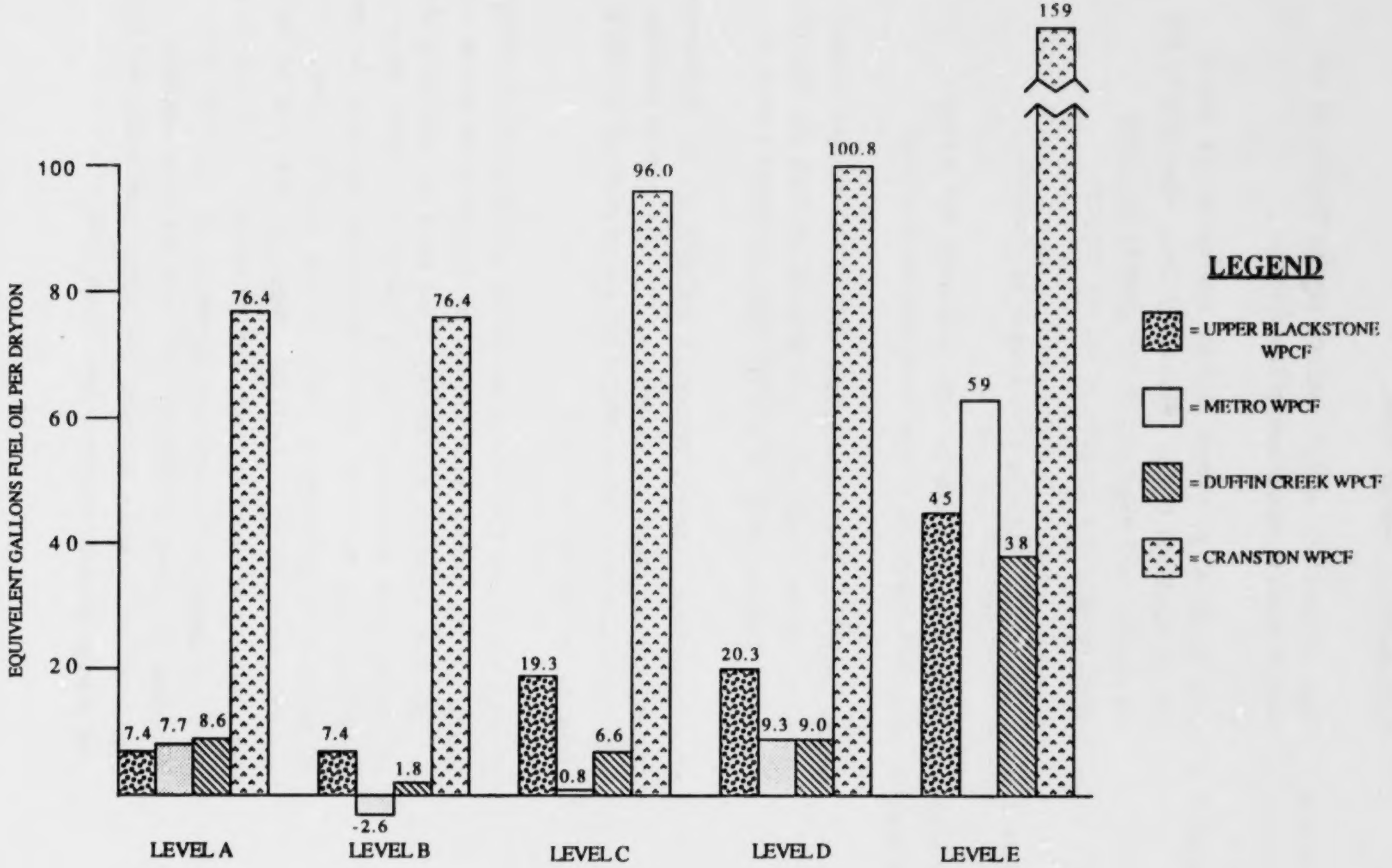


Figure 2. Comparative Consumption Levels A to E

- If the definition of the incineration system is expanded to include the sludge conditioning/dewatering system, the goal of net energy production by the incineration system does not appear achievable (Level D).

- Total energy consumption for a solids train utilizing sludge incineration can vary widely depending on the thickening and dewatering technologies utilized. Based on the results of this evaluation, total energy consumption for a well-operated solids train may range from 5 million to 9 million Btu per dry ton (5.8 million to 10.4 million kJ per dry tonne) of sludge cake processed (Level E).

- Overall, the evaluation demonstrates that a variety of technologies can achieve energy-efficient sludge incineration. The most complex systems (Duffin Creek and Metro) proved to be very energy efficient under each set of conditions evaluated. The simplest system (Upper Blackstone) also proved to be very energy efficient, especially in terms of overall energy consumption by the entire solids train (Level E).

SECTION 3
PLANT INFORMATION

The following four facilities have been evaluated as part of this study:

1. Upper Blackstone WPCF, Worcester, MA
2. Metro WPCF, Minneapolis, MN
3. Duffin Creek WPCF, Toronto, Canada
4. Cranston WPCF, Cranston, RI

This section provides an overview of the technology used at the four facilities and discusses the major technical and managerial aspects that contribute to each facility's successful operation. A more-detailed evaluation of the cost and energy requirements for each facility is included in Section 4 and Section 5 of this report.

UPPER BLACKSTONE WPCF

Plant Overview

The Upper Blackstone WPCF is a secondary wastewater treatment facility located in Millbury, MA. Treatment processes in the liquid train include aerated grit removal, primary settling, aeration, final settling, and chlorination prior to discharge to the Blackstone River. The solids handling processes include flotation thickening of the waste activated sludge, storage and mixing of the waste activated and primary sludges, blending, belt filter press dewatering of the blended sludges, sludge incineration, and ash disposal by landfilling. The facility went into operation in 1976. The plant was designed to treat an average day flow of 56 MGD (2,500 L/s). Currently, the facility treats an average flow of 36 MGD (1,600 L/s) and processes approximately 30 dry tons (27 dry tonnes) per day of dewatered sludge cake. A schematic of the solids train is shown in Figure 3.

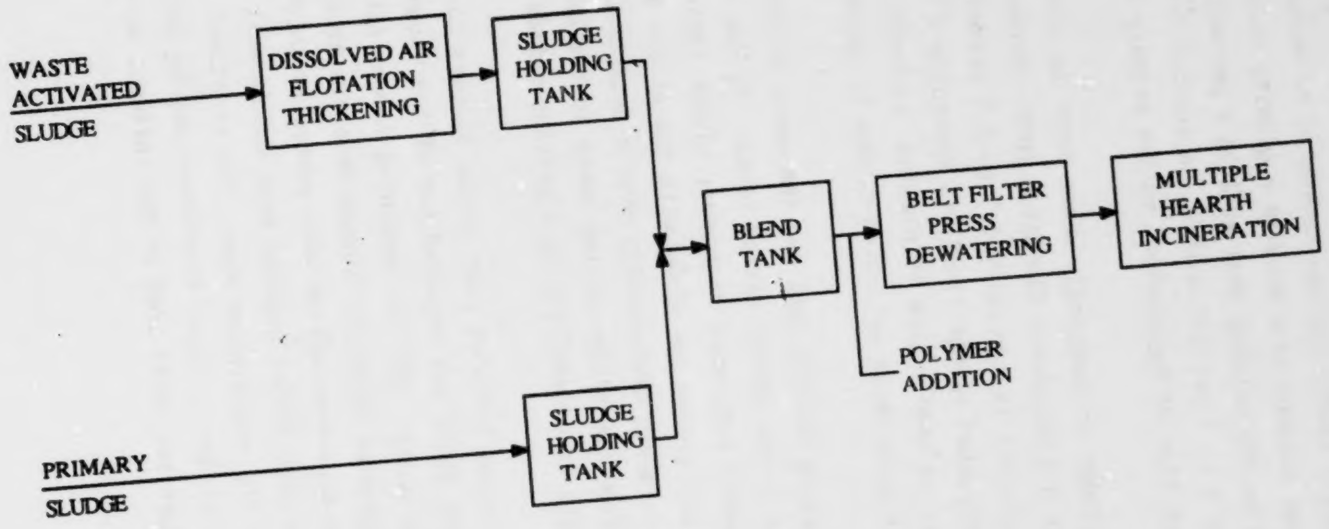

WASTE
ACTIVATED
SLUDGE
DISSOLVED AIR FLOTATION THICKENING
SLUDGE HOLDING TANK
PRIMARY
SLUDGE
SLUDGE HOLDING TANK
BLEND TANK
POLYMER ADDITION
BELT FILTER PRESS DEWATERING
MULTIPLE HEARTH INCINERATION

Figure 3. Upper Blackstone WPCF Solids Handling Schmatic.

Solids Processing

The solids handling train includes two sludge holding tanks, one dedicated to primary sludge and one dedicated to waste activated sludge. The primary sludge holding tank acts as a gravity thickener. Typically, sludge is pumped to the holding tank at 1 to 2 percent solids and leaves the tank at about 5 to 7 percent solids. A gravity overflow line returns a constant flow of supernatant to the primary settling tanks.

Waste activated sludge is constantly drawn from the final settling tanks and pumped to four dissolved-air flotation (DAF) thickeners. The DAF feed from the clarifiers is typically 0.7 to 0.8 percent solids. The thickened waste activated sludge (TWAS) is typically 4 to 5 percent solids. No polymer is used before thickening, although the equipment to do so exists. Thickened waste activated sludge is pumped to storage.

Sludge from the primary holding tank and the waste activated sludge holding tank is fed to two sludge mixing tanks. Sludge is pumped to the mixing tanks at a waste activated to primary sludge ratio of about 1.6 : 1 by volume. Scum and grease are mixed with the sludge at these blend tanks. The sludge is mixed mechanically over a detention time of about 3 hours. The feed from the sludge mixing tanks to the belt filter press (BFP) dewatering units is generally 5 to 6 percent solids.

The original plant design included four vacuum filters for sludge dewatering. The plant staff has replaced two of the vacuum filters with two belt filter press units. The two remaining vacuum filters are no longer used. The sludge at Upper Blackstone dewaters exceptionally well. A feed of 5 to 6 percent solids will generally thicken to 10 to 12 percent across the belt filter gravity zone and dewater to about 27 percent solids across the compression zone. The excellent dewaterability of the sludge at Upper Blackstone may be partially attributed to the industrial waste load in the influent stream.

Incineration System

Upper Blackstone has three multiple-hearth furnaces. Each furnace has 10 hearths. None of the furnaces is equipped with heat recovery systems. The incineration system is operated round the clock, seven days per week. The incineration process is extremely fuel efficient. The system frequently operates autogenously for extended periods of time and annually consumes approximately seven gallons of fuel oil per ton (29 L/tonne) of dry solids, including start-up and cool-down periods. Operators are given a great deal of flexibility in how to control the furnace, but are given the following common set of goals:

- maintain a minimum combustion temperature of 1250°F (675°C) to control air emissions.
- do not allow the combustion temperature to exceed 1500°F (815°C) to prevent clinker formation and avoid refractory damage
- burn as little auxiliary fuel as possible
- maintain a minimum oxygen level of 8 percent (dry basis) to insure complete combustion and avoid smoke in the stack exhaust
- maintain hearth no. 4 as the combustion hearth

The variables adjusted to achieve these goals are left to the operator's discretion. The operator monitors the furnace by observing the stack exhaust, opening doors on the furnace to observe the fire itself, and observing the hearth temperature profile and oxygen level from the control panel. It is important that the operator observe the fire directly at times and not rely completely on temperature sensors because localized hot or cool spots may result in misleading readings. Operators generally control the furnace by adjusting the flow rate of combustion and cooling air. Top-hearth exhaust temperatures range from 800°F to 1000°F (426°C to 537°C). Particulates are removed by a venturi wet scrubber and impingement tray scrubber arranged in series with a pressure drop of 20 inches (51 cm) w.c. Ash is landfilled on-site.

Keys To Success

Operating experience at Upper Blackstone provides the following insights into fuel-efficient incineration operation.

Storage and Mixing -

The use of storage and mixing tanks to maintain a consistent sludge feed to the dewatering and incineration processes is essential to avoid system upsets that would result in the use of auxiliary fuel. A uniform sludge feed is required to maintain optimum feed conditions.

Job Rotation Program -

The Upper Blackstone facility has installed a job-rotation program in which operators are moved to a different area of the plant every two weeks. The plant staff believes that the job-rotation program has been a very effective management tool. It allows operators to understand and appreciate how the efficiency of a process is affected by the preceding unit and helps relieve the boredom and complacency that can result from operating the same piece of equipment each day. The job-rotation program encourages teamwork and focuses the operator's attention on the overall goal of saving fuel in the incineration system rather than on the operation of an individual process.

Maintenance -

The implementation of a strong maintenance program is essential to fuel-efficient operation. During the facility's early years of operation, furnaces had to be removed from service frequently because of minor maintenance problems. During this period, the easy to check, high-profile items were being addressed during maintenance shutdowns, while less obvious, but equally important, maintenance items were being overlooked. These frequent shutdowns were very costly in terms of auxiliary fuel and labor.

To eliminate this, the plant staff instituted a regular preventive-maintenance program. The program has two main features - a regular rotation schedule and a detailed checklist. The rotation schedule provides for rotation of the furnaces every six months between operating, maintenance, and standby modes. The detailed checklist consists of 210 items that must be addressed during a furnace's maintenance shutdown period (see Appendix). Maintenance personnel consider the development of this checklist as a turning point in their operation. During each maintenance period, every item on this checklist must be checked and signed off by a maintenance worker and supervisor. This checklist system insures that minor items that can be easily overlooked are addressed during each maintenance shutdown period. Since the implementation of this checklist procedure, the furnaces have regularly been able to stay in service for the full six-month operating period, thus reducing unscheduled shutdowns to a minimum and reducing auxiliary fuel use for heat-up and cool-down periods.

Temperature Control -
Consistent temperature profile and maintaining controlled heat-up and cool-down periods should be maintained. As a result of this strategy, the 12 year old furnaces have never suffered any significant refractory damage.

Preventive Maintenance -
Plant management believes that the plant's success is a tangible result of their philosophy regarding operation and maintenance.

Plant management is willing to pay the annual cost of properly operating and maintaining the solids train in order to avoid periodic large cost repair items. At Upper Blackstone, management believes that the annual cost of proper system maintenance is a good investment in reducing the incineration system's life-cycle cost.

The development of an excellent maintenance program has increased the cost-effectiveness and fuel efficiency of the incineration process in several ways:

1. Decreasing auxiliary fuel use by minimizing unscheduled maintenance shutdowns. These shutdowns increase fuel use because of the fuel needed for startup.

2. Decreasing costs for replacement materials by extending the useful life of furnace components such as refractory brickwork and ancillary equipment.

3. Providing the operators with the information necessary to operate the incinerators fuel-efficiently by keeping the instrumentation and monitoring equipment operable and up-to-date in terms of current technology. This insures that the operators receive the information required to operate the furnace in an energy-efficient, environmentally sound manner.

METROPOLITAN WPCF

Plant Overview

The Metropolitan Waste Control Commission (MWCC) owns and operates 12 wastewater treatment facilities serving the Twin Cities (Minnesota) Metropolitan Area, the largest plant of which is the Metropolitan (Metro) Wastewater Treatment Facility. The Metro plant has undergone several upgrades since its original construction in 1938. From 1980 to 1983, the solids processing facilities underwent a major renovation aimed at improving the fuel efficiency of the incineration process. During that period, the incinerators were completely shutdown and the sludge was land applied. Today, the upgraded facility is in full operation and all sludge produced at the facility is incinerated.

The secondary wastewater treatment system has the capacity to treat an average day flow of 250 mgd (11,000 L/S) and a peak flow of about 375 mgd (16,400 L/s). The primary treatment system is designed to treat up to 655 mgd (28,700 L/s). The plant currently receives an average flow of 220 mgd (9,600 L/s) and peak flows as high as 700 mgd (30,700 L/s). Plant influent averages about 220 mg/L BOD and 200 to 250 mg/L TSS. Approximately 180 dry tons (163 tonnes) of dewatered sludge cake are processed at the plant daily.

Solids Processing

Sludge handling processes include thickening, sludge storage, heat conditioning (Zimpro), decanting, dewatering, and incineration. A schematic of the solids train is shown in Figure 4.

The facility contains 6 gravity thickeners and 12 dissolved air flotation thickeners. Primary sludge is gravity thickened along with the bottom sludge from the dissolved air flotation thickeners (DAF) and the sidestream flow from the roll press dewatering system. Gravity thickener influent is increased from about 0.5 percent solids to between 6 and 7 percent solids. Waste activated sludge is thickened by dissolved air flotation. The waste-activated sludge is thickened from about 0.75 to 1 percent solids to about 3 percent solids. Polymers are not used.

Sludge storage is provided before thermal conditioning. The storage tanks receive all the thickened waste activated sludge and about 35 percent of the thickened primary sludge. The stored sludge is mixed with air. The remaining 65 percent of the primary sludge bypasses the heat conditioning process.

The 8 Zimpro heat-conditioning units are operated at 380°F (193°C) and 325 psig (2.2 kPa). Each has a capacity of about 40 gpm (2.52 L/S). About 4,200 lb/hour (1905 kg/hr) of steam are required for each unit. This steam is provided by the waste heat recovery boilers. The Zimpro heat exchangers are cleaned with nitric acid on a regular basis to avoid scaling. Typically, four reactors are in operation and four are in reserve.

The heat conditioned sludge is conveyed to decanting tanks. The decanting process produces a sludge with 12 to 13 percent solids. Overflow from the decant tanks is treated by a rotating biological system (RBC units) before return to the primary clarifiers. Odorous gases from the decant tanks are used as combustion air in the multiple-hearth furnaces (MHF). Sludge produced by the RBC system is returned to the DAF thickeners for treatment and disposal.

The heat conditioned sludge and the primary sludge that bypasses heat conditioning are mixed in blend tanks before dewatering. The blended sludge is dewatered on 4 Ingersoll-Rand Vari-Nip twin-roll presses. About 18 pounds of cationic polymer is used per ton of dry solids (9 kg/tonne). Cake solids average 32 percent. A drier cake could be produced by directing a larger percentage of the primary sludge to the heat conditioning process. However, the staff has found that the optimum cake solids for the MHF system is 31 to 34 percent solids. A drier cake results in burning in the upper hearths of the MHF units and makes the furnace difficult to control.

In addition to the roll presses, eight diaphragm filter presses and eight vacuum filters are available for sludge dewatering. In the year considered by this evaluation (1987), the roll presses were used exclusively for sludge dewatering.

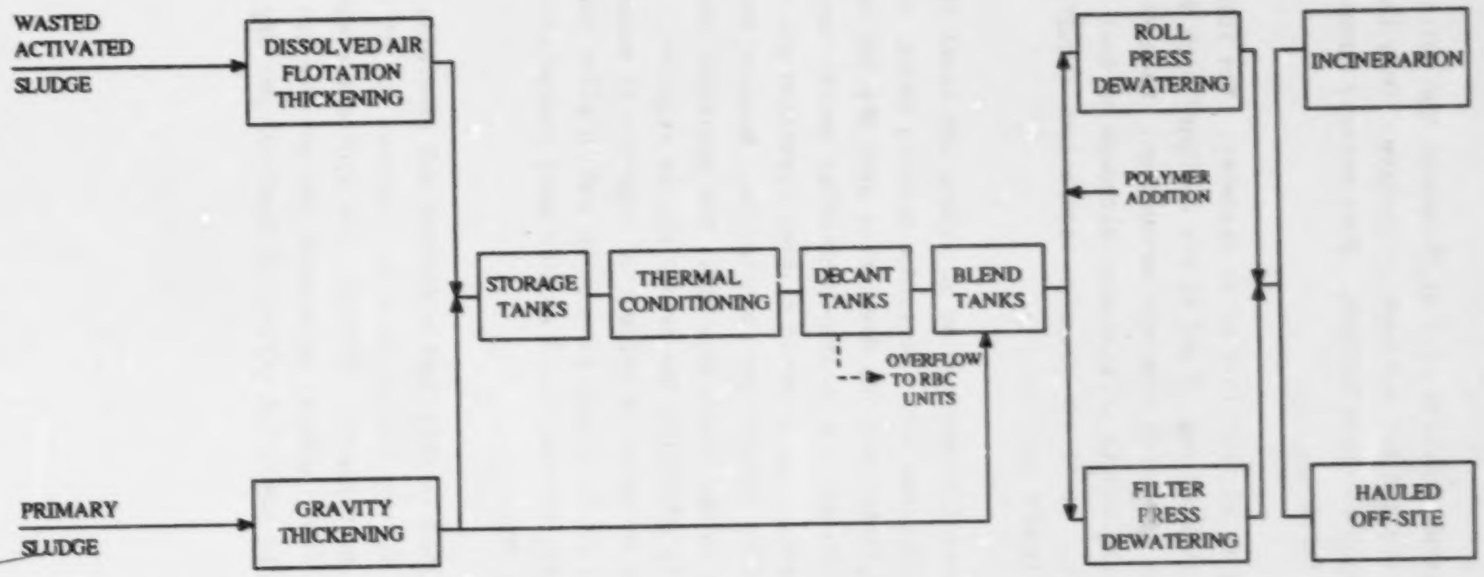

WASTED ACTIVATED SLUDGE
PRIMARY SLUDGE
DISSOLVED AIR FLOTATION THICKENING
GRAVITY THICKENING
STORAGE TANKS
THERMAL CONDITIONING
DECANT TANKS
OVERFLOW TO RBC UNITS
BLEND TANKS
POLYMER ADDITION
ROLL PRESS DEWATERING
FILTER PRESS DEWATERING
INCINERARION
HAULED OFF-SITE

Figure 4. Metro WPCF Solids Handling Schematic

Incineration System

The incineration system consists of 6 eight-hearth MHF units. Four of these units are active and two are kept as reserve. Only the four active units have heat recovery systems. Four retired furnaces are also located within the facility.

Each active furnace is 22 feet (6.7 m) in diameter. The furnace combustion hearths (hearth nos. 3 and 4) are designed with double the normal hearth volume to insure complete combustion. Each furnace is configured with a zero hearth afterburner, although no fuel is ever added at this hearth. State air emission regulations require an exhaust gas temperature of 1000°F (537°C).

The furnaces are generally operated at an excess air level of about 200 percent. Odorous off-gases from the sludge holding tanks, the thermal conditioning decant tanks, and the dewatering area are fed to the furnaces as combustion air. A maximum combustion hearth temperature of 1600°F (870°C) is maintained to avoid clinker formation and maintain the required 1600°F (870°C) exhaust gas temperature. Because the system is generally operating in the autogenous mode, the operators generally control the system by adjusting the excess air as required. Furnaces are generally loaded at about 75 percent of capacity to accommodate short term fluctuations in sludge production and to allow for the feeding of a drier sludge that would require more combustion/cooling air at the same loading rate.

The incineration system is very fuel efficient and generally operates autogenously. Fuel is required to take the furnaces out of service for regularly scheduled maintenance. Overall, the system averages about 1100 cubic feet (31 cubic meters) of natural gas per dry ton of sludge, which is equivalent to about 7.6 gallons of fuel oil per dry ton (32 L/tonne) of sludge.

Scum is pumped from the primary tanks to three skimming tanks, where it is separated from the transport water. The scum is decanted and heated in a decant hopper. The decanted scum is macerated and fed to the combustion hearth at a rate of 60 to 100 gallons (227 to 379 liters) per hour. Scum entering the furnace must be carefully metered to prevent sudden temperature fluctuations within the furnace. Operator communication and tight control of the sludge feed and excess air supply are necessary to maintain control as scum is pumped into the furnace. The scum has a heating value of about 15,000 Btu per pound (33,1000 Btu/kg) of liquid.

The Metro staff has implemented a very effective maintenance program aimed at discovering and correcting minor equipment problems before the problems become major problems. Each month, the entire dewatering and incineration system is taken out of service for an intensive, 16-hour maintenance overhaul. All equipment and instrumentation is reviewed during these shutdowns. Once each year, the entire solids handling train is taken out of service for a more detailed maintenance inspection. This annual shutdown is scheduled for the summer months when sludge production is low. These shutdowns are possible because the solids train was designed with adequate sludge storage and excess process capacity.

Heat is recovered from the furnace exhaust gas stream by a waste heat boiler system. In addition to the typical waste heat boiler, the plant staff has added an economizer section that increases the energy efficiency of the heat recovery system. Steam is generated by the waste heat boilers at 425 psig (2.9 kPa). The steam is used for the following applications:

First Priority - Provide of required Zimpro steam

Second Priority - Drive steam turbines for furnace induced-draft (ID) fans, water pumps, and auxiliary boilers. This reduces steam pressure from 425 psig (2.9 kPa) to 125 psig (0.9 kPa).

Third Priority - Satisfy plant heating requirements. Exhaust steam from the ID fans is used a second time to provide building heat. This second use reduces steam pressure from 125 psig (0.9 kPa) to 15 psig (0.1 kPa).

The waste heat boilers always generate enough steam to meet the needs of the thermal conditioning process. If additional steam is available, second and third priority demands are also met. An auxiliary boiler system is used to supplement the steam production by the waste heat boiler system for second and third priority uses.

Air emissions control is achieved with a venturi wet scrubber with a 30 inch (76.2 cm) w.c. pressure drop and a packed tower with 2 to 3 inches (5 to 7.6 cm) w.c. pressure drop arranged in series. Flue gases pass sequentially through the waste heat boiler and economizer, a pre-cooler, a venturi scrubber, a sub-cooler, a mist eliminator, and the ID fan. Ash is landfilled at an on-site ash pit.

Keys To Success

Operating experience at the Metro facility provides the following insights into fuel-efficient incineration operation.

Storage -
Storage in the solids train is essential. Storage helps the operator maintain a steady sludge feed to the incinerator in terms of quality and quantity and it allows the staff to completely shut down the incineration system for short periods of time on a regular basis to perform maintenance tasks.

Communication -
Communication between operators of different processes, between the operators and the maintenance crews, and between operators on different shifts helps develop consistency in the system's operation

and creates an atmosphere of cooperation among the entire staff. The Metro staff forms committees comprising engineers, maintenance personnel, and operators to address specific process problems. These committees produce innovative solutions to difficult problems and serve to encourage communication among the plant staff.

Motivation -
Management has created a very positive work environment at the Metro plant. By encouraging employees to pursue technical advancement through advanced education and professional organizations and by providing the staff with a budget that allows for experimentation and process improvements, management has developed a very motivated staff that is always looking for new ways to improve the solids handling processes.

DUFFIN CREEK WPCF

Plant Overview

The Ontario Ministry of the Environment owns and operates the Duffin Creek Water Pollution Control Plant, a secondary wastewater treatment plant serving greater Toronto. The facility began operation in 1980. It currently has a treatment capacity of 48 million U.S. gallons per day (2,100 L/s). Three future expansions are planned which will increase the capacity to 192 mgd (8,400 L/s). The first of these plant expansions is now under construction. Currently, Duffin Creek treats an average day flow of 47 mgd (2,100 L/s) and processes about 26.6 dry tons (24.1 dry tonnes) per day of dewatered sludge cake. A schematic of the solids processing train is shown in Figure 5.

Solids Processing

At the Duffin Creek facility, waste activated sludge is returned to the primary clarifiers and co-settled with the primary sludge. The co-settled sludge is drawn off the clarifiers at 5 percent solids and sent to a two stage anaerobic digestion system (four digesters total). Retention time in the digesters is about 20 days. The digesters serve to provide (1) sludge feed equalization to dewatering and sludge disposal; (2) digester gas, which is used as a source of fuel for preheating combustion air in the furnace hot-windbox and for the auxiliary boiler system; and (3) an effective means of blending scum into the sludge. In addition, the digested sludge is much less odorous than raw sludge. This eliminates the need for odor control in the dewatering and incineration areas. The digestion process reduces the volatile content of the sludge from 60 percent to about 40 percent.

The digested sludge is stored and then fed to 4 diaphragm filter presses. The filter presses replaced belt filter presses. The belt filter press units produced a cake with 21 to 22 percent solids. This was not dry enough to achieve autogenous combustion. To reduce fuel use, the plant staff replaced the belt filter press units with the filter presses.

The sludge feed to the diaphragm filter presses is conditioned with polymer. The filter press cake averages about 32 percent solids. The filtration/diaphragm squeeze time for each cycle is about 2 hours. Total cycle time including preparation time and other downtime averages about three hours. Each press cycle produces about one dry tonne (1.1 dry ton) of cake.

The cake must be conveyed from the dewatering building to the incineration building. The original installation included a series of horizontal and vertical screw conveyors, the longest of which was about 200 feet (61 meters). This system worked well with the belt filter press cake (22 percent solids), but could not handle the filter press cake (33 percent solids). The increase in cake dryness resulted in frequent maintenance shutdowns from bearing failures. As a result, a concrete-type slurry pump was installed on a trial basis. The pump

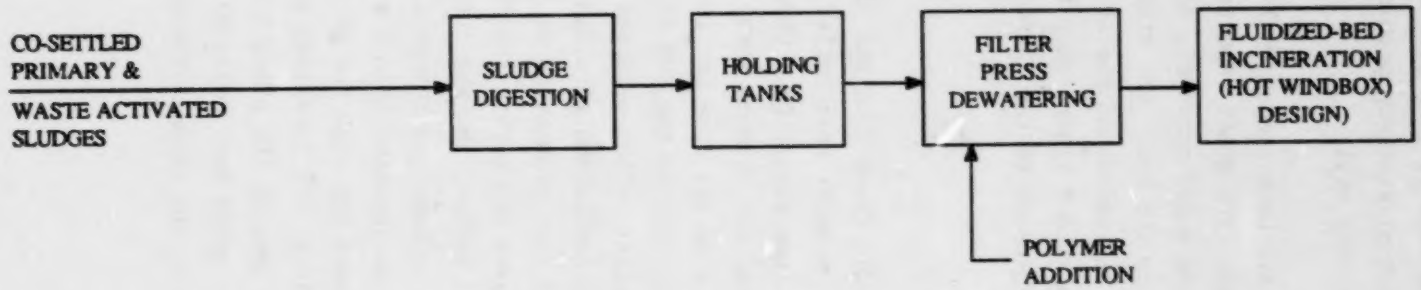

CO-SETTLED
PRIMARY &
WASTE ACTIVATED
SLUDGES
SLUDGE DIGESTION
HOLDING TANKS
FILTER PRESS DEWATERING
POLYMER ADDITION
FLUIDIZED-BED INCINERATION (HOT WINDBOX) DESIGN)

Figure 5. Duffin Creek WPCF Solids Handling Schematic

conveys the sludge cake about 500 feet (150 meters) through a pipeline from a storage hopper in the dewatering building to a storage hopper in the incineration building. The cake is then screwed into the furnace bed. After overcoming some initial start-up problems (pipe diameter too small), the pump has performed very well.

The staff believes that there are both operational and maintenance benefits to the pipeline system. The staff reports that the pipeline is neater and less odorous than the screw conveyor, and that the cake burns better when pumped directly into the bed. The staff now uses the slurry pump on a full-time basis and has abandoned the screw conveyors. The plant staff plans to install a second slurry pump to pump cake from the storage hopper preceding the furnaces to the furnace bed.

Incineration System

The incineration system at Duffin Creek consists of two fluidized bed furnaces (hot windbox design), a waste heat boiler system, a venturi scrubber, and a tray scrubber (see Figure 6). Under normal operation, digester gas is used to fuel the hot windbox (HWB), which preheats the combustion (fluidizing) air. Flue gas from the furnace passes through the heat exchanger, to transfer heat to the HWB air feed. The flue gas then passes to a waste-heat boiler, which produces steam to be used for building heat and to drive the combustion (fluidizing) air blowers. If the HWB temperature is so high that preheating of the HWB air feed is not necessary, the hot flue gases can bypass the heat exchanger and be fed directly to the waste heat boiler, thereby increasing steam production. The high furnace exhaust gas temperature (1560°F/850°C) and lengthy freeboard retention time (greater than 5 seconds) insure complete combustion and eliminate the need for an afterburner. To supplement the waste-heat boilers, two auxiliary boilers are available to (1) make up the difference between the plant's heating requirements and the heat production of the waste heat boilers; and (2) provide steam during start-up periods to drive the steam turbines that power the combustion air blowers.

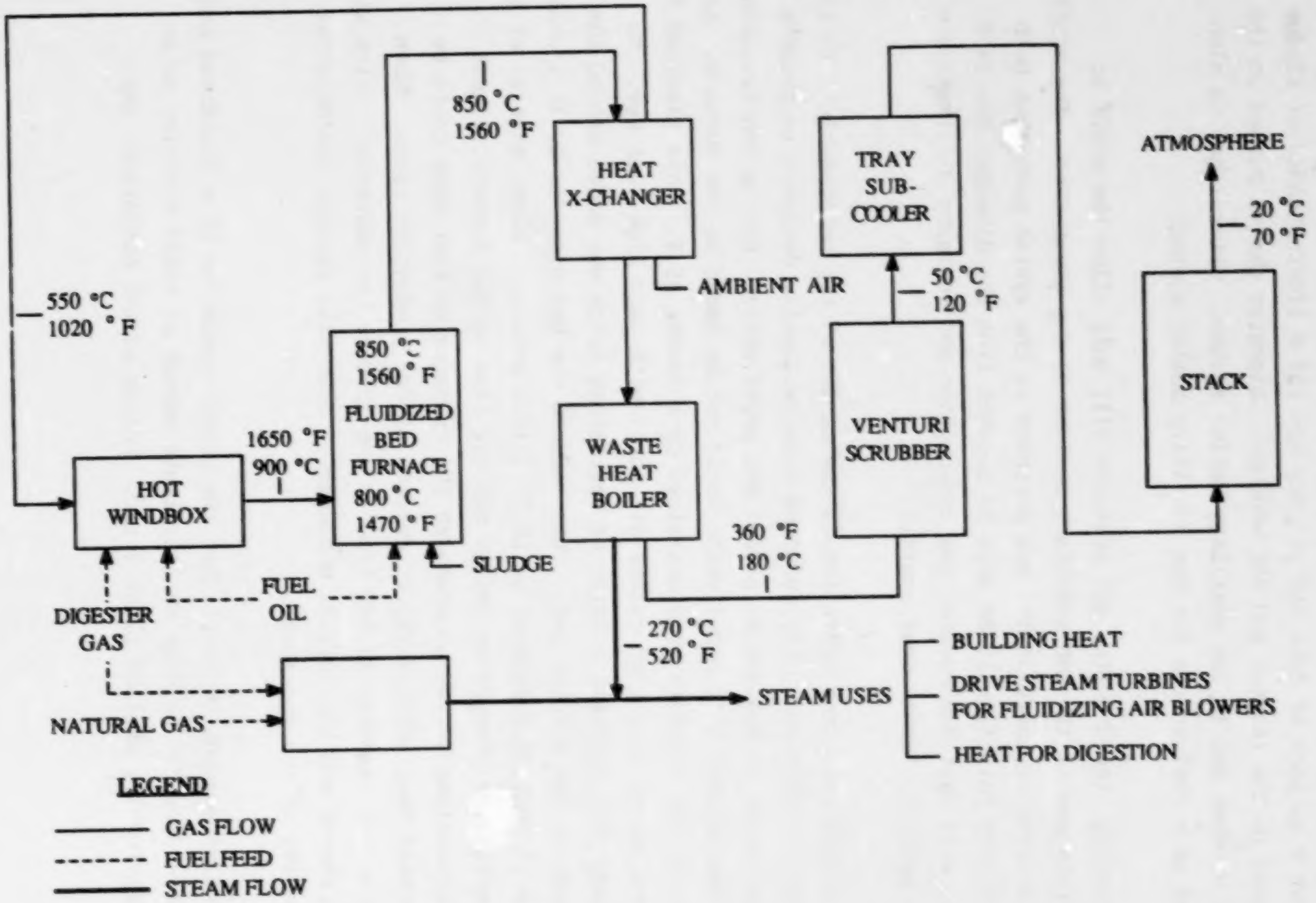

HEAT X-CHANGER
TRAY SUB-COOLER
ATMOSPHERE
850 °C 1560 °F
550 °C 1020 °F
20 °C 70 °F
AMBIENT AIR
50 °C 120 °F
850 °C 1560 °F
STACK
FLUIDIZED BED FURNACE
800 °C 1470 °F
1650 °F 900 °C
VENTURI SCRUBBER
WASTE HEAT BOILER
HOT WINDBOX
360 °F 180 °C
SLUDGE
FUEL OIL
DIGESTER GAS
270 °C 520 °F
BUILDING HEAT
DRIVE STEAM TURBINES FOR FLUIDIZING AIR BLOWERS
STEAM USES
NATURAL GAS
HEAT FOR DIGESTION
LEGEND
GAS FLOW
FUEL FEED
STEAM FLOW

Figure 6. Duffin Creek WPCF Incineration System Schematic

The incineration system now operates very fuel efficiently. Under normal operation, the combustion process is almost always autogenous. Some fuel is used to take the furnaces in and out of service. Overall, about 9 gallons of fuel oil per dry ton (37.6 liters/tonne) of sludge is burned in the reactor and hot windbox. Digester gas is burned in the hot windbox and in the auxiliary boiler system. Natural gas is also used as a fuel source for the auxiliary boiler system.

Currently, the digester gas pressure will only allow the staff to operate one of the two auxiliary boilers at any given time. The staff is working to increase the gas pressure in the system such that both auxiliary boilers will be able to operate from the digester gas feed. This will decrease natural gas consumption and increase utilization of the system's "free" fuel source.

This fuel-efficient operation is the result of two modifications to the original reactors. The furnaces were originally designed to process a combination of wastewater sludge and paper waste. During construction, it was decided that paper waste would not be added to the furnace. As a result, the furnaces were oversized by a factor of 4. This resulted in operation at very high excess air rates with very high fuel use. To remedy this problem, a layer of refractory brick was added around the inside of the furnace bed. This reduced the bed diameter by 36 inches from 18 feet (5.5 meters) to 15 feet (4.6 meters). Also, several of the tuyeres were plugged to reduce the air flow to the furnace. These modifications served to downsize the furnaces so that they could be operated fuel efficiently at current sludge production rates. When additional capacity is required in the future, the refractory brick will be removed and the tuyeres unplugged. This will restore the original capacity of the furnaces.

Plant management believes that the proper operation of a fluidized-bed system does not require an inordinate amount of staff training or an exceptionally skilled plant staff. During normal operation, the operator will monitor the hot-windbox temperature, the bed temperature, and the oxygen level in the flue gas to detect changes in the furnace's operating condition. Furnace temperature and the flue-gas oxygen level vary in response to changes in the percent solids or the percent volatiles of the feed. The operator can react to these changes in sludge quality by adjusting the air feed rate, adjusting the sludge feed rate, or by modulating the auxiliary fuel rate to the reactor burners. The plant staff reports that the feed to the furnace is kept fairly constant in terms of sludge quality and quantity due to the sludge storage and blending provided within the solids train. This makes the furnace easier to operate; major adjustments in the control variables are rarely required.

A reactor is generally operated as the lead furnace for one year and then taken completely out of service for a two-month maintenance overhaul. Once each week, the incineration system is taken out of service for four hours for a maintenance check. All instrumentation and equipment that is accessible is checked and calibrated. No fuel is required to restart furnace operation, because the sand bed retains heat.

Emissions control is achieved with a wet scrubber and cooling tower arranged in series. No afterburner is required. Wet ash removed by the scrubbing system is gravity thickened, dewatered to about 60 percent solids using a vacuum filter, and landfilled.

Keys To Success

Operating experience at the Duffin Creek Water Pollution Control Plant offers several insights into fuel efficient incineration.

Digestion -
Experience at Duffin Creek demonstrates that digestion can be part of a successful incineration process. The digesters serve several

functions. They provide storage within the solids train, offer an excellent means of incorporating scum into the sludge, produce a sludge that can be dewatered without an odor problem, and produce an end product (digester gas) that can be used as a fuel source in the incineration system. These positives must be balanced against the negative impact of the destruction of combustibles prior to incineration.

Conveyance System -
Experience at Duffin Creek shows that the means of conveying the sludge to the incinerator is a critical part of the solids train that should not be overlooked in design. The conveyance system must be dependable and have the capacity to meet the system's demands. Breakdowns in the conveyance system result in furnace shutdowns which require auxiliary fuel. Cement-type pumps are a viable option to screw conveyors.

Heat Storage -
The heat storage in the fluidized bed reactor provides additional protection against system upsets. This heat storage allows the operators to shutdown the system for short periods of time without auxiliary fuel use. This makes it easier to perform regular maintenance on the furnace and allows the operators to run the furnace at an optimum feed rate rather than try to lengthen the runs with a light feed rate to avoid shutdowns.

Fluidized-Bed Technology -
The plant staff reports that a fluidized bed furnace is easy to operate and control. There are few operation parameters to monitor and the heat sink built into the furnace provides protection against system upsets resulting from changing sludge quality. Proper operation of the system does not require an inordinate amount of staff training.

CRANSTON CASE STUDY

Plant Overview

The Cranston Water Pollution Control Facility is a secondary wastewater treatment facility designed to treat sanitary, industrial, and septage wastes from the City of Cranston, Rhode Island. An upgrade of the original primary treatment facilities was completed in 1981. Treatment processes in the upgraded liquid train include screening, aerated grit removal with detritors, grease flotation, primary settling, biological secondary treatment utilizing the activated-sludge process, and chlorination.

An upgrade of the sludge dewatering and thickening systems was completed in 1985. An upgrade of the incineration system was completed in 1986. The present solids handling processes consists of gravity and dissolved-air flotation thickening, storage, mixing, chemical conditioning with lime and ferric chloride, filter press dewatering, and multiple-hearth incineration. Digesters from the original facility are now used as sludge holding tanks. The incineration system is operated intermittently, and these storage tanks are used to store thickened sludge during periods when the dewatering/incineration system is off-line. During periods when the incineration system is taken out of service for an extended period of time, dewatered sludge cake is hauled off-site for landfilling.

The upgraded facility is designed to handle an average day flow of 23 mgd (1,000 L/s). Currently, the facility treats an average flow of 10 mgd (400 L/S) and processes about 9 tons (8.2 tonnes) per day of dewatered sludge cake. A plant schematic of the solids processing train is shown in Figure 7.

Plant operations at the Cranston Facility are currently in a state of transition. Following the completion of the upgrade to the solids train in 1986, the gravity and dissolved-air flotation thickeners were rarely used, because of operation and maintenance problems. During this period, secondary sludge was returned to the primary clarifiers and co-settled with the primary sludge. The thickening units were by-passed and sludge was sent directly to the sludge blend tank and the subsequent filter press dewatering process.

In June of 1988, several process changes were implemented. The gravity and dissolved air flotation thickeners were put back into service. The primary and secondary sludges are now settled and thickened separately and blended prior to dewatering, although equipment breakdowns have forced the facility to operate in the co-settling mode at times. Plant management reports that the facility has at times been understaffed. Because of these process changes and staffing problems, the operation of dewatering and incineration systems has not yet been optimized.

Solids Processing

The solids handling train begins with separate thickening of the primary and waste activated sludges utilizing gravity thickeners and dissolved-air flotation thickeners, respectively. The sludge feed to the gravity thickeners averages between one and two percent suspended solids and the sludge feed to the dissolved-air flotation thickeners averages about .5 percent suspended solids. The concentration of the individual thickened sludges is not measured.

Thickened sludge is fed either to a sludge storage tank or to a sludge blend tank. Currently, the dewatering and incineration system is operated on a five day per week schedule because of low sludge production. Sludge produced and thickened over the weekend is stored in two sludge storage tanks that were formerly used as digesters and fed to the dewatering/incineration processes during the following week.

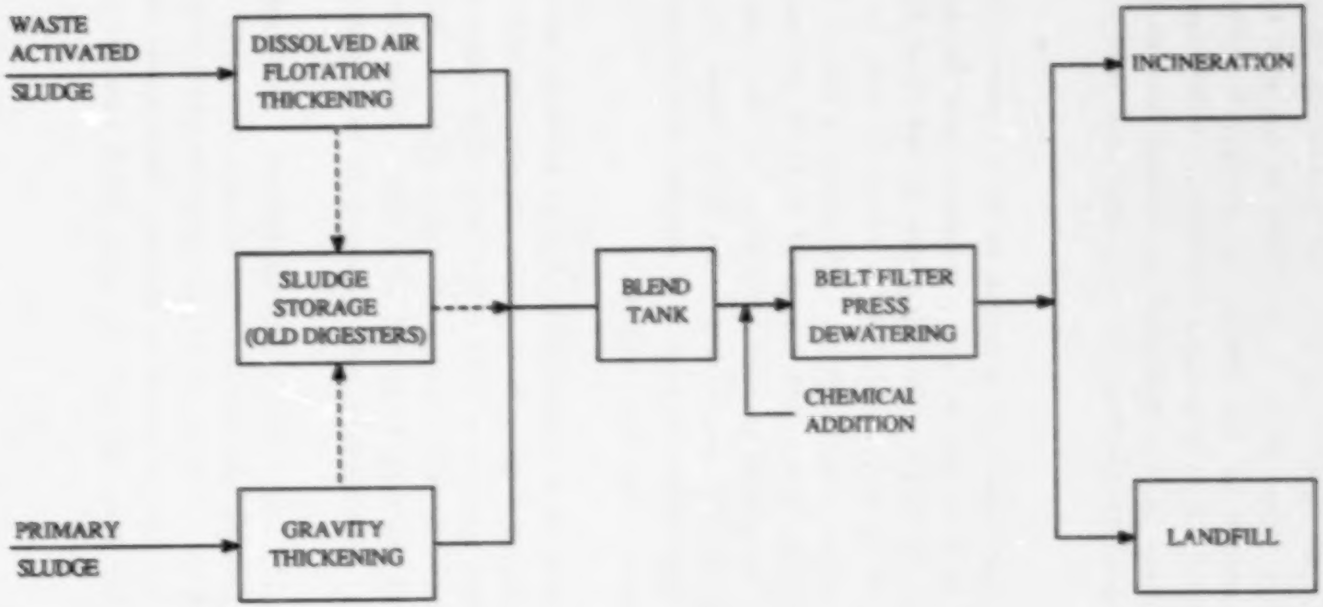

WASTE
ACTIVATED
SLUDGE
DISSOLVED AIR
FLOTATION
THICKENING
SLUDGE
STORAGE
(OLD DIGESTERS)
PRIMARY
SLUDGE
GRAVITY
THICKENING
BLEND
TANK
CHEMICAL
ADDITION
BELT FILTER
PRESS
DEWATERING
INCINERATION
LANDFILL

Figure 7. Cranston WPCF Solids Handling Schematic

Generally, fresh sludge is processed on Monday and Tuesday and weekend sludge is paced into the system at midweek. This mode of operation has a negative impact on the dewatering/incineration system. When weekend sludge is mixed into the dewatering feed, the quality of the sludge changes significantly. This makes it difficult to optimize the chemical conditioning requirements for the dewatering process; therefore the effectiveness of the dewatering process decreases. Under these conditions, the furnace is very difficult to control because the concentration and volatile fraction of the sludge cake feed are fluctuating.

The sludge feed to the blend tank averages about 3.5 percent solids, but can range from 1.5 to 5 percent solids. Detention time in the blend tanks averages about 16 hours. Blended sludge is fed first to chemical conditioning tanks where ferric chloride is added and then to flocculation tanks where lime is added. Typically, a ferric chloride dosage of 6 to 7 percent and a lime dosage of 15 to 20 percent are used. A polymer conditioning system is also available, but the lime and ferric conditioning system is used exclusively. The staff hopes that future improvements in polymer effectiveness will someday make polymer a viable conditioning alternative for their system.

Sludge is dewatered in three fixed-volume filter presses, each with 104 plates (105 chambers), 1.5 meter by 2 meter. Plates are made of cast iron. Volume of each chamber is 2.17 cubic feet (0.06 cubic meters) and total press volume is 228 cubic feet (6.46 cubic meters). The filter presses operate at a pressure of 90 psi (0.6 kPa). Press time varies from 2.5 to 4 hours. The product cake averages 26 to 27 percent solids.

Each filter press discharges into a storage bunker. The purpose of the bunkers is to provide the equalization storage necessary to transform the batch output from the filter press dewatering process into a continuous feed for the incineration system. Each bunker has a usable capacity of 900 cubic feet (25 cubic meters), which equates to almost four filter press loads of 228 cubic feet (6.46 cubic meters) each. In practice, the usable capacity of these bunkers has been severely limited because of bridging problems. To avoid bridging, the operators store no more than about half a pressload in any one bunker.

Under each bunker is a conveyor that transports the cake to a surge bin which precedes each furnace. A weigh belt is installed to insure that a consistent mass of cake is withdrawn from the surge bins and fed to the furnaces. However, the weigh belt is only able to deliver a consistent mass of cake if the density of cake remains consistent. Variations in the quality of the sludge cake (septic sludge from storage tanks versus fresh sludge) results in variations in the furnace feed rate. Also, probes within the storage bins which are intended to control the conveyor feed rate are not always operable. Problems with this conveying system have at times shutdown the entire dewatering/incineration system.

Incineration System

The incineration system consists of two six-hearth furnaces. One is a Crouse unit that was installed as part of the plant upgrade and went on-line in 1986. One is a Nichols furnace that is about 40 years old, but was rarely used until the upgraded incineration facility went on-line in 1986. The new Crouse furnace is the larger of the two furnaces, with a diameter of 18.75 feet (5.7 meters). The smaller Nichols furnace has a diameter of 14.25 feet (4.3 meters). Each furnace has an external afterburner chamber and a separate scrubbing and heat recovery system. The furnaces were designed for operation in the pyrolysis (starved air) mode, but have only operated in this manner during start-up.

The older (and smaller) Nichols furnace was operated full time from start-up in spring of 1986 to the fall of 1987. At that time, several problems forced the staff to take the Nichols furnace out of operation. Among the problems were center shaft damage, refractory damage, and damage to rabble teeth on hearth No. 1 and No. 2. Since that time, the Crouse furnace has been used exclusively.

The Crouse furnace is severely underloaded and therefore is difficult to operate in a fuel-efficient manner. The furnace is operated on a 5 day per week schedule at a loading rate of approximately 3200 wet pounds (1450 kg) of dewatered cake per hour. The staff has found that the optimum feed rate for the furnace is about 5,200 wet pounds (2360 kg) of sludge cake per hour but, because of a lack of sludge, the furnace is almost always operated at less than optimum feed rates.

Typical sludge cake requires auxiliary fuel for combustion of the relatively low solids and volatiles content of the sludge feed. Unscheduled system shutdowns due to equipment failures have also hampered the fuel efficiency of the incineration operation. These shutdowns, both scheduled and unscheduled, and the quality of the sludge feed result in the equivalent of 76 gallons of fuel oil consumption per dry ton (317 liters/dry tonne) of sludge cake.

Top-hearth gases pass through an external afterburner chamber, although no auxiliary fuel is used. The staff reports that the combustion temperature averages about 1300°F (704°C) and the top hearth temperature averages 850°F to 900°F (454°C to 482°C). Gases then pass through a waste heat exchanger (currently off-line), a variable-throat venturi scrubber, and an inpingement tray scrubber/sub-cooler before discharge to the atmosphere. The scrubbing system is designed for a pressure drop of 25 inches (63.5 cm) W.C. The heat exchanger transfers heat at a hot gas/heating oil interface and then at a heating oil/water interface. The final product is hot water which can be used for space heating throughout the plant. This system was put into operation in the Fall of 1987. The system worked successfully in the 1987/1988 heating season, but in June 1988 had to be taken off-line due to a severe corrosion problem. The system has not yet been put back into operation.

Keys To Success

The design and operating experience at Cranston WPCF offers several insights into fuel efficient sludge incineration.

Consistent Sludge Feed -
Operators at the Cranston facility emphasize the importance of consistency in the operation of the incineration system. Any changes to the system should be made gradually. A consistent sludge feed is essential to fuel-efficient operation.

Operation Schedule -
Operation of a multiple-hearth furnace on a five day per week schedule is very costly because of the fuel required to maintain stand-by temperatures over the week-end. Unscheduled shutdowns due to maintenance problems also significantly increases auxiliary fuel use.

Storage Design -
Sludge hoppers should be designed to avoid bridging. A large fraction of the sludge storage at Cranston is lost because bridging.

SECTION 4

ECONOMIC COMPARISON OF FACILITIES

BASIS OF ANALYSIS

To develop a meaningful economic comparison between the four subject facilities, the raw cost data included in the appended case-study reports must be put into a format that allows an equal comparison between facilities. To accomplish this, the effect of variations in plant capacity, variations in each facility's current loading condition, and variations in each facility's unit costs for labor and consumables must be eliminated to the extent possible. Costs particular to a specific facility such as the cost to treat an exceptionally strong sidestream flow or the cost credit for heat recovered from the incineration process must be accounted for in the analysis. This section describes the methodology developed to account for these factors and presents the findings.

Limits of The Solids Handling/Heat Recovery System

In general, the solids handling train considered extended from the clarifiers through the incineration system. Specifically, this evaluation considered all capital and operation and maintenance costs relating to the following unit processes:

Upper Blackstone WPCF

- Pumping of the primary and waste activated sludges from the clarifiers through the solids train
- Flotation thickening of the waste activated sludge
- Storage and mixing of the waste activated and primary sludges
- Polymer sludge conditioning

- Sludge dewatering utilizing belt filter press units
- Sludge incineration utilizing multiple hearth incineration
- Air emission control
- Ash disposal

  Note that capital costs for the original sludge dewatering system (vacuum filtration) are not included in this evaluation.

Metropolitan WPCF

- Pumping of the primary and waste activated sludges from the clarifiers through the solids train
- Gravity thickening of the primary sludge
- Flotation thickening of the waste activated sludge
- Storage and mixing of the waste activated and primary sludges
- Thermal sludge conditioning of the blended primary and waste activated sludges
- Decanting of the thermally conditioned sludge
- Treatment of the decant tank overflow using a rotating biological system (RBC units)
- Polymer sludge conditioning
- Sludge dewatering utilizing roll presses
- Sludge incineration utilizing multiple hearth furnaces
- Air emission control
- Ash disposal
- Heat recovery utilizing a waste heat boiler system
- Operation of an auxiliary boiler system to supplement the waste heat boiler system

  Note that capital costs for equipment that was not in use during the study period (stand-by and retired dewatering technologies and retired incinerators) are not included in the evaluation.

Duffin Creek WPCF

- Pumping of the primary and waste activated sludges from the clarifiers through the solids train
- Sludge digestion
- Polymer sludge conditioning
- Sludge dewatering utilizing diaphragm filter presses
- Sludge incineration utilizing fluidized bed furnaces
- Air emissions control
- Ash disposal
- Heat recovery utilizing a waste heat boiler system
- Operation of an auxiliary boiler system to supplement the waste heat boiler system

  Note that capital costs for the original sludge dewatering system (filter presses) are not included in this evaluation.

Cranston WPCF

- Pumping of the primary and waste activated sludges from the clarifiers through the solids train
- Gravity thickening of the primary sludge
- Flotation thickening of the waste activated sludge
- Sludge storage and blending of thickened waste activated and primary sludges
- Chemical sludge conditioning utilizing lime and ferric chloride
- Sludge dewatering utilizing fixed-volume filter presses
- Sludge incineration utilizing multiple hearth furnaces
- Air emissions control
- Ash disposal

  Note that costs relating to the heat recovery system are not included in this evaluation. The heat recovery system was not in operation during the study period.

The solids handling processes at each of the four facilities produce a filtrate stream that must be returned to the head of the plant for treatment. This return load typically totals 5 to 10 percent of the influent BOD and TSS loading. At the Upper Blackstone, Duffin Creek, and Cranston facilities, the load from the sidestream flow falls into this typical range. At the Metro facility, the sidestream flow is of much higher strength due to the heat conditioning process and must be treated to reduce its strength before it can be returned to the head of the plant. The cost to treat the sidestream flow that is returned to the head of the plant is considered to be equal at the four facilities, and this cost is not considered in the evaluation. The higher level of sidestream treatment required at the Metro facility represents an additional cost to the solids handling system that must be accounted for in the economic evaluation. For this reason, the capital and operation and maintenance costs associated with the rotating biological treatment (RBC) system used for sidestream treatment at the Metro facility are included in the economic evaluation.

The incineration systems at both the Metro and Duffin Creek facilities include waste heat recovery. This recovered heat is used to generate steam, which is used in several applications throughout each facility. Some of these applications are external to the incineration system (i.e. provide building heat) and therefore represent an energy output from the incineration system. This energy output should be accounted for as a cost credit to the incineration system. Some of the steam is consumed within the incineration system (i.e. to drive fluidizing air blowers or induced-draft fans) and, therefore, its use does not constitute a cost credit. The waste heat recovery systems at the Metro and Duffin facilities were reviewed to determine which applications should qualify as a cost credit to the incineration system.

Plants with waste heat recovery systems must have an auxiliary boiler system to supplement steam generation from the waste heat boilers during periods of low sludge production or high steam demand. The auxiliary boiler system is considered a part of the incineration/heat recovery system; therefore fuel input to the auxiliary boilers and steam generated by the auxiliary boilers is accounted for under the incineration system. For the purposes of this evaluation, costs to operate the waste heat and auxiliary boilers were included under costs for the incineration system. The value of the recovered heat used in other areas of the facility was credited to the incineration system.

At the Metro facility, steam generated by the waste heat recovery system is used in the following applications:

1. To provide 100% of the steam required for the thermal conditioning process.
2. To drive steam turbines for the furnace induced draft fans, boiler feedwater pumps, auxiliary boilers, and some miscellaneous turbines.
3. To provide building heat throughout the facility.

Some steam is used twice, once in a high-pressure application and a second time in a low-pressure application. For example, steam may be used first to drive the induced-draft fans, which reduces steam pressure from 425 psi to 125 psi (2.9 kPa to 0.9 kPa) and then to provide building heat, which reduces steam pressure from 125 psi to 15 psi (0.9 kPa to 0.1 kPa).

Because the Metro thermal conditioning process is part of the incineration system, the conditioning process is not "charged" for the steam received from the furnace waste heat recovery system. Steam used to drive turbines for the induced draft fans, boiler feedwater pumps, and auxiliary boilers is also considered an internal system use; therefore no cost or energy credit can be taken for these applications.

Steam used to drive miscellaneous turbines outside of the incineration system and steam used to feed the plant heating loop is considered to be an energy output from the incineration system. A cost credit for this energy is taken by the incineration system. The amount of this cost credit is determined as follows:

- For steam used to drive miscellaneous turbines external to the incineration system, the cost credit is based on the equivalent electrical cost to drive these turbines.

- For steam used to provide building heat, the cost credit is based on the cost to generate an equivalent amount of steam using auxiliary boilers.

At the Duffin Creek facility, steam generated by the waste heat recovery system is used in the following applications:

1. To drive steam turbines that power the furnace fluidizing (combustion) air blowers.
2. To provide heat for the digestion process.
3. To provide building heat throughout the facility.

Steam used to drive the fluidizing air blowers is an internal use; therefore no credit is taken for this application. Heat provided to the digestion process is also considered an internal system use, therefore no credit is taken for this application. The digestion process provides digester gas to the incineration system for use as a "free" fuel source and the incineration process provides "free" heat to the digestion process. The free use of digester gas as a fuel source compensates the incineration system for the loss of volatiles within the digestion process. Steam used to feed the plant heating loop is considered to be an energy output from the incineration system; therefore a credit is taken for this application. The cost credit is based on the cost to generate an equivalent amount of steam using auxiliary boilers.

Operation & Maintenance Costs

Operation and maintenance costs for each facility were obtained through a review of plant records and discussions with each plant staff. For the Duffin Creek, Metropolitan, and Upper Blackstone facilities, 12 months of complete plant records spanning from 1987 to 1988 were available. Because of the process and personnel changes at the Cranston facility since mid 1988, only six months of usable plant records were available.

Cost data were broken down into six categories; (1) labor; (2) electricity; (3) fuel (either fuel oil or natural gas); (4) chemicals; (5) materials and supplies; and (6) contracted services. Each category is defined and discussed below.

Labor -
Labor costs at each facility were determined through an evaluation of plant records and discussions with plant management. Plant records were used to determine total labor costs for the entire solids train and average labor rates (including benefits) for each plant staff. Plant management at each facility estimated the typical allocation of labor for each unit process.

Electricity -
Although the intent of this project was to present actual cost and energy data based upon plant records, the lack of available data made this task impossible at three of the four facilities evaluated. Only the Metro facility has records of actual metered electrical consumption broken down by unit processes, and even in this case there is no way to segregate equipment consumption from general consumption for lights, HVAC, and other building needs. The Cranston, Upper Blackstone, and Duffin Creek facilities essentially have one electrical meter for the entire facility with no means of breaking down the total consumption at the facility into each unit processes.

In each of the appended case-study reports, an equipment list including connected horsepower and typical hours of operation for each piece of equipment was developed. However, several factors make it difficult to develop accurate estimates of electrical consumption based upon connected horsepower. For instance, a filter press may operate 24 hours per day, but the filter press feed pump and other ancillary equipment only operate a small fraction of that time. Also, equipment such as an induced-draft fan may in fact be operating 24 hours per day, but very rarely operates at its maximum connected horsepower. As a result, estimates of electrical consumption that are based upon connected horsepower are generally inflated.

Because of the lack of plant data and the problems associated with estimating electrical consumption based upon connected horsepower, the following methodology regarding electrical consumption was adopted:

1. Records of actual metered electrical consumption were used for the Metro facility. Note that these metered figures include both equipment related electrical consumption and consumption for building-related requirements such as lighting and HVAC.

2. Electrical consumption for the Cranston, Upper Blackstone, and Duffin Creek facilities was estimated as follows:

    - The building area allocated for each unit process was estimated.

    - Electrical requirements for building-related energy consumption (heating, cooling, lighting, and ventilation) were estimated based upon an annual requirement of 40 kWh/square foot/year (430 kWh/square meter/year). This number represents an average consumption figure based upon data presented in the EPA publication entitled Energy Conservation in Municipal Wastewater Treatment (4).

- Electrical requirements for thickening and dewatering equipment were estimated based upon the following typical values:

Dissolved Air Flotation (DAF) Thickening	60 kWh/ton	(66 kWh/tonne)
Gravity Thickening	0.25 kWh/ton	(0.27 kWh/tonne)
Sludge Digestion	60 kWh/ton	(66 kWh/tonne)
Belt Filter Press Dewatering	15 kWh/ton	(16.5 kWh/tonne)
Filter Press Dewatering	30 kWh/ton	(33 kWh/tonne)

All of these values are taken from the Water Pollution Control Federation Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities (5). Estimates of electrical consumption for chemical conditioning are based upon curves presented in this same reference.

- Electrical consumption for sludge pumping was estimated based on upon curves presented in the EPA publication entitled Energy Conservation in Municipal Wastewater Treatment.

- Electrical consumption for sludge storage was estimated based upon curves presented in the EPA publication entitled Estimating Sludge Management Costs (6).

- Electrical requirements for the incineration systems at the Cranston and Upper Blackstone facilities was based upon curves presented in the EPA Process Design Manual Sludge Treatment and Disposal (7). These curves cannot be used to estimate electrical consumption at the Duffin facility because the major source of electrical consumption in the Duffin incineration system, the fluidized air fan, is steam driven. Therefore, electrical consumption for the Duffin incineration system was based upon connected horsepower, excluding the fluidized-air fan.

This methodology was checked for reasonableness by applying the procedure outlined above to the Metro facility and comparing estimated electrical consumption figures to actual consumption figures. Using this methodology, estimates of the Metro facility's electrical consumption came within 3 percent of the actual consumption measured at the facility.

Based on this test, the methodology applied to estimate electrical consumption is thought to be reasonable.

Fuel -

This category includes fuel oil and natural gas consumed by the furnaces and the auxiliary boiler system. All fuel consumption figures are based upon plant records.

Chemicals -

At each facility, the major chemical consumption is for sludge conditioning before dewatering. At the Duffin Creek and Metro facilities, a small quantity of chemicals is also used within the incineration system for boiler feedwater preparation. All consumption figures are based upon plant records.

Materials & Supplies -

This category refers to miscellaneous materials and supplies purchased by the plant staff for maintenance purposes. Included in this category are costs incurred for retractory repair, replacement of rabble teeth, repairs to heat exchangers, and other equipment overhaul costs. Estimates of this cost item are based upon plant records and discussions with the plant staff.

Contracted Services -

This category includes outside consultants or contractors used by the plant staff to assist in operation and maintenance tasks. Costs in this category can vary widely from plant to plant. The Metro and Upper

Blackstone facilities rarely use outside contractors for O&M purposes. The Cranston facility uses outside contractors extensively because of a shortage of in-house staff. The Duffin facility uses outside contractors to assist in general housekeeping and clean-up duties. Estimates of this cost item are based upon plant records and discussions with the plant staff.

Estimating Capital Costs

Capital cost data also present several problems. Accurate capital cost information for any facility is very difficult to obtain and, even if accurate data are obtained, it is very difficult to compare capital cost data from different facilities. There are several problems inherent to any evaluation of capital costs. Often, records regarding original capital costs are incomplete or difficult to interpret. Some facilities are bid as a large lump sum contract and capital costs for individual unit processes are not available. Some facilities are constructed in stages, making it difficult to accurately piece together information from a series of contracts spanning several years. In some instances, it is possible to get accurate original cost information, but the facility is so old that it is questionable as to whether the costs can be updated accurately using available cost indices.

The four facilities included in this study were selected, in part, in an effort to minimize these potential problems. The four selected facilities all had very complete records of original capital costs and the management at each facility was very helpful in interpreting this information. Still, it is inevitable that the problems outlined above influenced this evaluation to some extent.

Assuming that accurate capital cost information could be obtained from each facility, several additional problems make it difficult to make a meaningful comparison of capital costs from different facilities. The capital costs for two similar facilities can be very different depending on site-specific factors such as subsurface conditions, local materials costs, site constraints, construction market conditions, and other construction considerations. The amount of reserve capacity built into a facility also significantly affects construction costs. The amount of reserve capacity allowed for in the design phase can depend on factors such as site-specific constraints, plans for future expansion, and the design consultant's and owner's philosophy regarding system redundancy. All these factors make it difficult to generalize about capital costs.

Original capital costs for each facility were updated to 1988 dollars using the Engineering News Record (ENR) cost index. At three of the four subject facilities, the original dewatering technology was subsequently replaced by a new technology. In these cases, capital costs for the replacement dewatering equipment were used so that equipment costs for each unit process were not double counted. Updated capital costs were amortized assuming a 40 year useful life for all structures, a 20 year useful life for all equipment, and a discount rate of 8 percent.

ADJUSTMENTS TO RAW COST DATA

Cost data from the four subject facilities cannot be used for comparison purposes in its raw form, because of (1) local and regional variations in unit costs for labor, electricity, fuel, and other consumables; and (2) differences between plant capacities and current plant loads.

Accounting for Variations in O&M Unit Costs

Because of local and regional variations in unit costs, some cost data from facilities located in different regions cannot be compared on an equal basis. The variation in unit costs can make a facility's operation and maintenance expenditures appear artificially high or low.

To account for the variations, operation and maintenance costs for the four facilities were converted to a common set of unit costs. This eliminated inequities resulting from variations in unit costs at the four facilities.

To select a reasonable set of standard unit costs for use in this evaluation, the unit costs from each facility were reviewed. These costs are presented in Table 3. Based on these data, the following set of standard unit costs were selected for use in this evaluation:

Labor	\$15.00 /hour
Electricity	\$ 0.045/kw-hour
Fuel oil	\$ 0.75 /gal (\$0.20/liter)
Natural Gas	\$ 4.00 /1000 cubic feet (\$0.14/cubic meter)

A standard unit value was developed for steam produced by the waste heat recovery systems at the Duffin Creek and Metro facilities. This value was to be based on the cost to generate an equivalent amount of steam using auxiliary boilers. Plant records at the Duffin facility are arranged such that the cost to operate and maintain the boiler system is included in the overall cost for the incineration system and cannot be easily segregated. However, plant records at the Metro facility clearly distinguish between operation and maintenance costs for the furnaces and operation and maintenance costs for the boiler system. From these records, it was determined that the overall cost for the Metro auxiliary boiler system to generate steam was about \$7.00 per 1000 lb. (\$0.15/kg) of steam, including fuel, labor, and materials and supplies. This figure is based on the standard unit costs. The cost credit computed for steam produced by the Duffin Creek and Metro incineration systems is based on this unit cost of \$7.00 per 1000 lb (\$0.15/kg).

TABLE 3

FACILITY UNIT COSTS

Item	Cranston WPCF	Metro WPCF	Upper Blackstone	Duffin Creek*	Average Cost
Labor ($/hour)**					
-Operations	$14.00	$18.00	$12.50	$14.71	$14.80
-Maintenance	$14.00	$22.00	$12.50	$14.71	$15.80
Electricity ($/kw-hour)	$0.060	$0.037	$0.047	$0.037	$0.045
Fuel Oil ($/gal)	—	$0.90	$0.59	$0.74	$0.74
Natural Gas ($/1000cf)	$6.30	$2.50	$3.56	$3.50	$3.97

* U.S. Dollars

** Includes benefits

1 gallon = 3.7854L
1 cubic foot = 0.028317 cubic meters

Some operation and maintenance costs, such as the cost for materials and supplies and the cost for contracted services, cannot be standarized. Chemical costs for sludge conditioning are also difficult to standarize because of the many variables that influence conditioning costs. Each facility has a different dewatering technology and therefore has different chemical conditioning requirements. However, the adoption of the standard unit costs outlined above does equalize the operation and maintenance costs for the four facilities to the extent possible.

Accounting for Different Capacities and Loadings

The current loads to the four facilities range from 9 dry tpd (8.2 dry tonnes per day) of dewatered cake to 177 dry tpd (161 dry tonnes per day) of dewatered cake. This large range in loading conditions introduces inequities resulting from economy of scale.

The load on a plant (versus design capacity) can have a significant impact on operation and maintenance costs. A system generally operates most cost efficiently when operating at or near its design capacity. For example, some processes require essentially the same operator attention, the same maintenance, and the same power consumption whether the process is lightly loaded or loaded to capacity. As a result, unit costs are less when operating at design capacity. For this reason, it a facility operating at design capacity should not be compared directly with a facility that is in the early stages of its design life.

Because of the influence of the difference between load and capacity, costs were evaluated for operation at current loads and for operation at capacity. To estimate the costs at capacity, the capacity of each solids handling system was estimated, and costs for operation at capacity were developed.

The capacity of each solids train was taken to be the maximum amount of sludge that the solids train could process while maintaining a reasonable amount of stand-by capacity. Applying a uniform definition of "reasonable stand-by capacity" to the four facilities eliminates inequities resulting from the variation in each facility's design reserve capacity.

The determination of the capacity of each solids train was based on engineering judgment. Each unit process in each solids train was reviewed with regards to capacity and the limiting process in each train was identified. It was assumed that a reasonable amount of stand-by capacity must be retained within the system. In some cases, the capacity of one unit process severely limited the capacity of the solids train as a whole. In these instances, it was assumed that the capacity of the limiting process would be expanded to match the capacity of the rest of the solids train. In these cases, the capital cost of the existing facility was added to the estimated capital for the additional equipment.

The Duffin Creek facility presented a unique situation regarding system capacity. As discussed in Section 3, capacity of the incineration system installed at the Duffin Creek facility exceeds the current sludge production. The furnaces were subsequently modified to operate efficiently at a reduced loading. The capacity of the existing solids train at the Duffin Creek facility is 30 dry tpd (27.2 dry tonnes per day) of dewatered sludge cake. However, the capacity of the existing furnaces could be expanded from 30 tpd (27.2 dry tonnes per day) per unit to 60 tpd (54.4 dry tonnes per day) per unit by returning the furnaces to their original installed capacity. No new construction or equipment installation would be required. It would be very difficult to accurately estimate the cost of the extensive construction that would be required to upgrade the digestion and dewatering systems to match the full capacity of the incineration system. Therefore, two capacity figures are used for the Duffin Creek Facility. The capacity of the Duffin Creek solids train is rated at 30 dry tpd (27.2 dry tonnes per day) of dewatered sludge cake and the capacity of the Duffin Creek incineration system is rated at 60 dry tpd (54.4 dry tonnes per day) of dewatered sludge cake.

The evaluation of each facility's system capacity is summarized as follows:

Facility	Estimated Capacity (dry tons of dewatered sludge)	Additional Equipment Required
Upper Blackstone WPCF	60 dry tons/day	additional belt filter press
Duffin Creek WPCF		
- digestion/dewatering	30 dry tons/day	none
- incineration	60 dry tons/day	none
Metro WPCF	240 dry tons/day	additional gravity thickener
Cranston WPCF	30 dry tons/day	additional gravity thickener

dry tons/day = 0.907 dry tonnes/day

Capital costs for the Duffin Creek facility were further adjusted to minimize the effect of excessive redundancy. The capacity of the existing Duffin dewatering system is about 30 dry tons (27.2 dry tonnes) per day, but the dewatering building was sized to accommodate a future expansion of the dewatering system. If the dewatering building had been sized to house only the existing dewatering equipment, the building size could be cut almost in half. To account for this excess building space, the structural cost for the Duffin dewatering system was adjusted to reflect the cost of the actual required building volume. This is the only instance in which building costs were adjusted to minimize the effect of oversized structures.

Each facility's expenditures for labor, electricity, chemicals, and other consumables were scaled up to reflect operation at capacity. Projections of design year operation and maintenance expenditures are based upon the raw costs data presented in the appended case study reports. Costs were scaled up based upon the percent increase in sludge production, the increase in the number of units on-line under average conditions, or some other appropriate parameter.

To project fuel consumption by the Metro and Duffin auxiliary boiler systems when operating at capacity, it was assumed that the same total amount of steam would be produced by the boiler systems, that the steam produced by the waste-heat boilers would increase in proportion to the projected increase in sludge production, and that steam production by the auxiliary boiler systems would decrease accordingly.

PLANT COMPARISONS

In this section, cost information on the four treatment plants is evaluated for the current operation (with the equipment not loaded to capacity) and for operation at capacity. Costs for the individual processes and for the total process train (from thickening through combustion) are analyzed. Cost information is presented on the basis of dry ton of dewatered sludge cake processed. Tables detailing capital and operation and maintenance costs for each facility under both current loading and capacity loading conditions are appended.

Sludge Thickening and Digestion

The Metro, Upper Blackstone, and Cranston facilities all employ gravity thickening of the primary sludge and flotation thickening of the waste activated sludges. The Duffin Creek facility utilizes sludge digestion. Per ton costs for these unit processes are presented in Tables 4 and 5.

These observations can be made:

- Capital costs for the Cranston facility are on the high end of the range because its gravity thickeners are housed. The Metro and

TABLE 4

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS FOR SLUDGE THICKENING ($/DRY TON)

	METRO (1)		UPPER BLACKSTONE (2)		CRANSTON (3)	
	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT
CAPITAL	$25.98	$ 35.13	$13.10	$26.10	$50.28	$165.77
LABOR	12.54	12.71	4.75	5.48	25.41	27.79
ELECTRICITY	7.23	9.10	4.10	4.80	3.87	10.36
FUEL	0.00	0.00	0.00	0.00	0.00	0.00
CHEMICALS	0.23	0.23	0.00	0.00	3.61	3.61
MATERIALS & SUPPLIES	4.35	4.41	0.39	0.39	3.65	6.02
CONTRACTED SERVICES	0.22	0.22	0.00	0.00	0.24	0.78
TOTAL O&M	24.57	26.68	9.24	10.67	36.79	48.56
TOTAL COST	$50.55	$61.81	$22.34	$36.77	$87.07	$214.33

1 dry ton = 0.9072 dry tonnes

The solids train capacity for each facility is estimated as follows:

Metro	240 tpd of dewatered cake
Blackstone	60 tpd of dewatered cake
Cranston	30 tpd of dewatered cake

Current average loading condition for each facility is estimated as follows:

Metro	177.5 tpd of dewater cake
Blackstone	30.1 tpd of dewatered cake
Cranston	9.1 tpd of dewaterd cake

(1) Includes sludge pumping from the clarifiers, flotation thickening of Waste Activated Sludge, and gravity thickening of primary sludge.

(2) Includes sludge pumping from the clarifiers, flotation thickening of Waste Activated Sludge, and storage of thickened W.A.S. and primary sludge. (Note that the primary sludge holding tank acts as a gravity thickener.)

(3) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and gravity thickening of primary sludge.

TABLE 5

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS FOR SLUDGE DIGESTION AT DUFFIN CREEK
($/dry ton)

	DUFFIN CREEK (1)	
	AT CAPACITY	CURRENT
CAPITAL	$ 54.19	$ 60.43
LABOR	5.04	5.50
ELECTRICITY	6.14	6.66
FUEL0	0.00	0.00
CHEMICALS	0.00	0.00
MATERIALS & SUPPLIES	0.75	0.75
CONTRACTED SERVICES	1.50	1.50
TOTAL O&M	13.42	14.42
TOTAL COST	$ 67.62	$ 74.85

1 dry ton = 0.9072 tonnes

(1) Includes sludge pumping from the clarifiers and sludge digestion.

Blackstone facilities have uncovered gravity thickeners. Capital costs for the Duffin Creek digestion system are greater than the typical sludge thickening capital cost.

- Labor costs vary widely among the four facilities. Costs for the Cranston facility are very high as a result of the many maintenance problems experienced by the thickening equipment.

- Cost of chemicals for flotation thickeners is highly dependent upon the characteristics of the waste activated sludge and can vary widely from plant to plant. Chemical costs for the Cranston facility are higher than the Metro facility. The Upper Blackstone facility does not employ any chemical conditioning.

- Cranston's high costs for thickening are expected. The staff has only operated the thickening equipment for a short period of time and is still in the process of optimizing the operation. Also, the thickening equipment has required a great deal of maintenance to be restored to working order.

- O&M costs for digestion at Duffin Creek are lower than the average cost for sludge thickening.

- Total costs for the Cranston facility are high for the reasons outlined above. Total costs for sludge digestion are comparable to the total costs for sludge thickening.

Sludge Conditioning And Dewatering

The Metro, Upper Blackstone, and Duffin Creek facilities all utilize polymer sludge conditioning before dewatering. The Metro facility also employs thermal sludge conditioning. Sludge dewatering at these three facilities is accomplished utilizing roll presses (at Metro), belt filter presses (at Upper Blackstone), and diaphragm filter presses (at

Duffin Creek). The Cranston facility utilizes lime and ferric chloride for sludge conditioning and fixed-volume filter presses for sludge dewatering. See Table 6 for costs.

The observations can be made:

- Capital costs for the Upper Blackstone facility are very low. At the Duffin Creek and Cranston facilities, most of the capital costs are dedicated to the dewatering equipment (filter presses), whereas at the Metro facility, most of the capital costs are dedicated to the sludge conditioning equipment.
- Labor costs for the Metro facility are higher than the other three facilities. The high labor cost at the Metro facility is attributable to the complexity of the sludge conditioning system.
- Chemical requirements are considerably less for Upper Blackstone than for Duffin Creek. Costs for lime and ferric sludge conditioning are much higher than for polymer conditioning costs.
- The low electrical cost for the Upper Blackstone facility reflects the low energy consumption of a belt filter press installation. The higher electrical cost at the Metro facility reflects the additional equipment and building space required for the thermal sludge conditioning process.
- Costs for materials and supplies contracted services are low for all four facilities.
- Labor and chemicals are the major cost items at each facility.
- Total conditioning/dewatering costs for the Upper Blackstone are very low. Costs for the other three facilities fall in a fairly narrow range, with amortized capital costs constituting about 40 percent of the total annual system cost.

TABLE 6

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS
FOR SLUDGE CONDITIONING/DEWATERING ($/DRY TON)

	METRO (1)		UPPER BLACKSTONE (2)		DUFFIN CREEK (3)		CRANSTON (4)	
	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT
CAPITAL	$ 65.26	$ 88.24	$ 18.47	$ 36.81	$ 47.95	$ 53.47	$62.64	$206.50
LABOR	49.43	51.47	19.75	25.79	39.45	39.60	19.28	33.84
ELECTRICITY	11.63	12.40	2.87	5.22	4.94	5.35	6.78	15.51
FUEL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHEMICALS	13.19	13.90	7.26	7.26	21.06	21.20	55.07	55.97
MATERIALS & SUPPLIES	6.97	7.14	2.37	2.37	10.77	12.01	7.67	16.26
CONTRACTED SERVICES	0.51	0.53	0.00	0.00	3.32	3.34	0.00	0.00
TOTAL O&M	81.73	85.44	32.24	40.64	79.54	81.50	88.79	121.57
TOTAL COST	$147.00	$173.68	$ 50.71	$ 77.45	$127.49	$134.97	$151.43	$328.07

1 dry ton = 0.9072 dry tonnes

The solids train capacity for each facility is estimated as follows:

Metro	240 tpd of dewatered cake
Blackstone	60 tpd of dewatered cake
Duffin	30 tpd of dewatered cake
Cranston	30 tpd of dewatered cake

Current average loading condition for each facility is estimated as follows:

Metro	177.5 tpd of dewater cake
Blackstone	30.1 tpd of dewatered cake
Duffin	26.9 tpd of dewatered cake
Cranston	9.1 tpd of dewatard cake

(1) Includes thermal sludge conditioning, roll press dewatering, and treatment of the thermal conditioning sidestream (RBC system)

(2) Includes polymer conditioning and belt filter press dewatering.

(3) Includes polymer conditioning and dewatereing with diaphragm filter presses.

(4) Includes conditioning with lime and ferric and dewatering with diaphragm filter presses.

Sludge Incineration

The Metro, Upper Blackstone, and Cranston facilities all have multiple hearth furnaces. The Duffin Creek facility has a fluidized-bed system. See Table 7 for costs.

These observations can be made:

- Capital costs for the Upper Blackstone facility are very low. Capital costs for the Metro and Duffin Creek facilities include waste heat and auxiliary boiler systems.

- The low labor cost at the Cranston facility is the result of a fewer staff compared to desired operation practice.

- Electrical costs are heavily influenced by the amount of building space allocated for the incineration system, because of electrical consumption for building needs such as lighting and HVAC.

- Total fuel costs have been broken down into fuel consumed in the furnace and fuel consumed in the auxiliary boiler system. Fuel consumption within the furnace, including cool-down and heat-up periods, is very low for the Metro, Blackstone, and Duffin Creek facilities. The Duffin Creek cost includes furnace fuel oil consumed both within the reactor and within the hot windbox. It does not include any cost for digester gas burned within the hot windbox. This is considered a free fuel source.

- Current furnace fuel consumption at the Cranston facility is very high. This is a result of the 5 day per week operation schedule, the frequent unscheduled maintenance shutdowns, the light furnace loading during operating periods, and the low volatility and solids concentration of the sludge cake. These shutdowns, both scheduled (weekends) and unscheduled, consume a great deal of auxiliary fuel.

TABLE 7

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS FOR SLUDGE INCINERATION ($/DRY TON)

	METRO (1)		UPPER BLACKSTONE (2)		DUFFIN CREEK		CRANSTON (3)	
	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT
CAPITAL	$124.58	$168.45	$ 47.56	$ 94.80	$ 93.74	$209.07	$118.02	$389.07
LABOR	59.40	63.68	29.45	29.45	29.78	50.75	19.42	42.78
ELECTRICITY	12.94	16.95	10.57	13.69	6.27	10.33	7.66	25.26
FUEL - FURNACES	4.16	4.22	4.65	4.65	6.46	6.46	7.50	42.15
- AUX BOILERS	7.19	14.58	—	—	0.45	21.04	—	—
CHEMICALS	0.86	0.86	0.00	0.00	2.50	2.51	0.00	0.00
MATERIALS & SUPPLIES	10.66	10.95	5.39	5.39	21.92	45.57	4.02	6.32
CONTRACTED SERVICES	1.81	1.76	0.00	0.00	13.97	17.70	17.69	44.50
COST CREDIT	17.62	23.82	0.00	0.00	6.20	13.84	0.00	0.00
TOTAL O&M	79.40	89.17	50.05	53.17	75.14	140.51	56.28	161.01
TOTAL COST	$203.98	$257.62	$ 97.61	$147.97	$168.88	$349.58	$174.30	$550.08

1 dry ton = 0.9072 dry tonnes

The solids train capacity for each facility is estimated as follows:

Metro	240 tpd of dewatered cake
Blackstone	60 tpd of dewatered cake
Duffin	60 tpd of dewatered cake
Cranston	30 tpd of dewatered cake

Current average loading condition for each facility is estimated as follows:

Metro	177.5 tpd of dewater cake
Blackstone	30.1 tpd of dewatered cake
Duffin	26.9 tpd of dewatered cake
Cranston	9.1 tpd of dewaterd cake

(1) Includes incineration, heat recovery, ash disposal, and auxiliary boiler systems.
(2) Includes incineration and ash disposal systems.
(3) Includes incineration, heat recovery, ash disposal, and auxiliary boiler systems.
(4) Includes incineration, heat recovery, and ash disposal system.

- The Blackstone facility uses no outside consultants for operation and maintenance tasks. The Metro facility very rarely uses outside consultants. The Duffin Creek facility utilizes outside contractors for general housekeeping duties and for ash disposal (tipping fee). The cost for contracted services is highest at the Cranston facility, reflecting the many major repairs that have been required at the facility and the current manpower shortage at the facility.

- As described previously, a cost credit is taken for steam generated by the waste heat/auxiliary boiler system that is used in an application external to the incineration system. The credit for the Metro facility is significantly higher than for the Duffin Creek facility. This is a reflection of the steam utilization at each facility. About 53 percent of the steam generated by the Metro system is used in applications outside of the sludge processing system, whereas only about 23 percent of the steam generated at the Duffin Creek facility is used in applications outside of the sludge processing system. At both facilities, steam used to drive combustion air fans results in a cost credit in the form of reduced electrical costs.

- Cranston's current total operation and maintenance costs are high as a result of excessive auxiliary fuel consumption and the frequent need for outside consultants. Cranston's projected per ton operation and maintenance costs for operation at system capacity are about 35 percent less than the current operation and maintenance costs. This wide range of costs is the result of the large difference between the current and capacity loading conditions. Fuel costs were adjusted to reflect future operation on a round the clock, seven day per week schedule with a minimum of system shutdowns.

- Costs for the Blackstone facility are very low. No major repairs have been required at the Blackstone facility; therefore costs for materials and outside contractors are minimal. The facility frequently operates autogenously; therefore costs for auxiliary fuel are very low. Costs for the Metro and Duffin Creek facilities fall in the middle of the cost range. Based on this information, a reasonable range of O&M costs for a well-operated sludge incineration facility is $70 to $90/dry ton ($77 to $99/dry tonne) for plants operating at capacity.

- It is interesting to note the impact that fuel consumption can have on total O&M costs. Many of the O&M costs for a facility are somewhat fixed, but auxiliary fuel costs can be directly influenced by operation practices. This is reflected in the O&M costs for these four facilities. At the facilities that operate autogenously much of the time, the cost of auxiliary fuel is a relatively minor O&M cost (less than 5% of total O&M costs). At the Cranston facility, auxiliary fuel costs are very significant, making up about 25% of the total O&M budget.

- Total system costs for the Upper Blackstone facility are exceptionally low, even for a well-operated facility. The other three facilities provide a more realistic range of costs for what one would expect from a well-operated facility. Costs for the Metro, Duffin, and Cranston facilities range from $169 to $204/dry ton ($186 to $224/dry tonne) at capacity. Based on this information, a reasonable estimate of total (capital and O&M) costs for incineration at a well-operated sludge incineration facility operating at capacity is about $200/dry ton ($220/dry tonne) of sludge cake processed.

Total Solids Handling Costs

Table 8 summarizes total capital and operation and maintenance costs for the entire solids train.

These observations can be made:

- Capital costs for the Upper Blackstone facility are exceptionally low and cannot be considered typical. If the costs for Blackstone facility are disregarded, the average capital cost for the remaining three facilities (operating at capacity) is $214/dry ton ($236/dry tonne) wit a fairly tight range of $196 to $231/dry ton ($216 to $255/dry tonne). Based on this information, a reasonable estimate of capital costs for a solids train incorporating sludge incineration is $200 to $230/dry ton ($220 to $254/dry tonne) when operating at capacity.

- Total operation and maintenance costs for Upper Blackstone are exceptionally low and cannot be considered typical. Based on information from the other three plants, a reasonable estimate of total O&M costs for a well-operated incineration solids train is $180 to $200/dry ton ($198 to $220/dry tonne) when operated at capacity.

- Total costs (capital and O&M) for Upper Blackstone are exceptionally low and cannot be considered typical. Based on information from the other three plants, a reasonable estimate of total annual costs (including capital) for a well-operated incineration solids train is $380 to $430/dry ton ($418 to $473/dry tonne) when operating at capacity.

A review of Table 8 shows consistently low costs for the Upper Blackstone facility. The exceptionally low operation and maintenance costs for the Blackstone facility can only be explained as the product of a small, highly skilled staff having fully optimized the operation of each unit process within the solids train. At each of the facilities evaluated, labor costs represent the largest single O&M item, especially if one considers the contracted services item as an extension of the staff labor cost. Upper Blackstone has been able to minimize labor

TABLE 8

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS FOR TOTAL SOLIDS TRAIN ($/DRY TON)

	METRO		CRANSTON		DUFFIN CREEK		UPPER BLACKSTONE	
	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT	CAPACITY	CURRENT
THICKENING/DIGESTION								
- CAPITAL	$ 25.98	$ 35.13	$ 50.28	$165.77	$ 54.19	$ 60.43	$ 13.10	$ 26.1
- O&M	24.57	26.68	36.79	48.56	13.42	14.42	9.24	10.67
- TOTAL	50.55	61.81	87.07	214.33	67.62	74.85	22.34	36.77
CONDITIONING/DEWATERING								
- CAPITAL	$ 65.26	$ 88.24	$ 62.64	$206.50	$ 47.95	$ 53.47	$ 18.47	$ 36.81
- O&M	81.73	85.44	88.79	121.57	79.54	81.50	32.24	40.64
- TOTAL	147.00	173.68	151.43	328.07	127.49	134.97	50.71	77.45
INCINERATION								
- CAPITAL	$124.58	$168.45	$118.02	$389.07	$ 93.74	$209.07	$ 47.56	$ 94.80
- O&M	79.40	89.17	56.28	161.01	75.14	140.51	50.05	53.17
- TOTAL	$203.98	$257.62	$174.30	$550.08	$168.88	$349.58	$ 97.61	$147.97
TOTAL SOLIDS TRAIN								
- CAPITAL	$215.82	$291.82	$230.94	$761.34	$195.88	$322.97	$ 79.13	$157.71
- O&M	185.70	201.29	181.86	331.14	168.10	236.43	91.53	104.48
- TOTAL	401.52	493.11	412.80	1092.48	363.98	559.40	170.66	262.19

1 dry ton = 0.9072 dry tonnes

The solids train capacity for each facility is estimated as follows:

Metro	240 tpd of dewatered cake
Blackstone	60 tpd of dewatered cake
Duffin	30 tpd of dewatered cake
Cranston	30 tpd of dewatered cake

Current average loading condition for each facility is estimated as follows:

Metro	177.5 tpd of dewater cake
Blackstone	30.1 tpd of dewatered cake
Duffin	26.9 tpd of dewatered cake
Cranston	9.1 tpd of dewaterd cake

costs by developing a well-rounded staff that is able to effectively operate and maintain the facility with an absolute minimum of people. The staff's optimization of each unit process has minimized the consumption of energy, chemicals, and other consumables.

Major factors contributing to the process efficiency at Upper Blackstone are the design of the facility and the characteristics of the sludge being processed at the facility. The design of the facility included equalization storage and sludge blending, both of which serve to minimize changes in the sludge quality and quantity. Also, the sludge at Upper Blackstone thickens and dewaters exceptionally well (E.G. 5-6% solids feed to dewatering and 27% solids cake product vs 23% solids cake at typical BFP facility). These factors make it easier for the staff to control and optimize each unit process in the solids train. This combination of an excellent staff, a well-designed facility, and a sludge with excellent dewatering properties has resulted in an extremely cost effective sludge processing system.

Table 8 also demonstrates that per ton costs for a facility can vary significantly depending on how the cost data are presented. The variation in per ton capital costs is directly related to the percent capacity currently utilized at each facility. For example, per ton capital costs for the Duffin Creek incineration system are about halved when projected to operation at capacity because the system is currently operating at about one-half of its capacity. Differences in per ton operation and maintenance costs are the results of the changes in process efficiency that a system experiences during its design life. Per ton operation and maintenance costs will always be least when the system is operating at capacity because of the increased efficiency of power, labor, materials, etc. that result from the complete equipment utilization.

This variation in system costs over the life of a facility should be considered when reviewing the tables presented in this study. During the life of each of these facilities, per ton operation and maintenance costs will vary significantly. This variation can be reduced through the use of multiple units rather than single large units in equipment selection, the accurate estimation of initial and design year sludge quantities, and other design features. However, every facility will be affected by this life-cycle cost variation to some extent.

SECTION 5

ENERGY EVALUATION OF FACILITIES

GENERAL

Energy efficiency is one of the primary measures of the success of a sludge incineration operation. Often, the terms "autogenous" or "self-sustaining" are used to describe the incineration process. Strictly speaking, these terms describe conditions in which no auxiliary fuel is required to maintain the steady-state condition within the furnace. The heat required to dry the incoming sludge, increase the dried sludge temperature to ignition temperatures, maintain the burn temperature, compensate for radiation losses within the furnace, and allow for complete combustion of all solids and gases is provided by the sludge itself.

For the purposes of determining eligibility for alternative technology grant funding preference, the EPA construction grants program defines self- sustaining incineration, differently, as follows:

> "In order to be eligible for the alternative technology grant funding preference, an incineration system must be a net energy producer or 'self-sustaining' (including the energy used for sludge dewatering, combustion and pollution control equipment). To meet this requirement, extremely energy efficient equipment and operating procedures (such as codisposal) have to be used for collecting and recovering heat energy" (8).

Clearly, there are there are several ways to evaluate the energy efficiency of an incineration system depending on how one defines the system's energy input and output. The analysis presented here will evaluate all energy inputs to and outputs from both the incineration system alone and the solids train as a whole. The information will be presented so that readers may draw conclusions regarding the energy efficiency of the incineration system, depending on how they choose to define the system's energy inputs and outputs. The evaluation will also allow a comparison of various sludge thickening, conditioning, and dewatering technologies and each solids handling system as a whole.

BASIS OF ANALYSIS

System Inputs & Outputs

Energy inputs and outputs for each of the four facilities can be broken down as follows:

Upper Blackstone
Energy Inputs - Electricity
- Natural Gas
- Fuel Oil

Energy Outputs - None

Metropolitan WPCF
Energy Inputs - Electricity
- Natural Gas

Energy Outputs - Steam

Duffin Creek WPCF
Energy Inputs - Electricity
- Fuel Oil
- Natural Gas

Energy Outputs - Steam

Internal Transfer - Digester Gas

Cranston WPCF

Energy Inputs	- Electricity - Natural Gas
Energy Outputs	- None

Note: A heat exchanger was installed at the Cranston facility to recover waste heat from the incineration system. However, the heat exchanger has experienced severe corrosion problems and therefore has not operated for a long enough period to evaluate its potential for energy recovery.

Evaluation of Plant Data

The evaluation of energy requirements is based on raw plant data. Energy consumption figures for each facility were determined as follows:

1. Electrical Consumption

   See discussion in Section 4 regarding the methodology used to estimate electrical consumption.

2. Consumption of Auxiliary Fuel

   Total consumption of auxiliary fuel for each facility was obtained directly from plant records. From the Metro plant records, auxiliary fuel consumption within the furnaces could be distinguished from fuel consumption within the auxiliary boiler system. For the Duffin Creek facility, fuel consumption within the incineration/auxiliary boiler system could not be broken down as easily. Duffin Creek plant records include total consumption figures for each form of auxiliary fuel, but do not distinguish between fuel consumed within the hot windbox, the furnaces, and the auxiliary boiler system. Discussions with the plant staff indicate that fuel oil is very rarely used other than in the furnace burners. Therefore, it will be assumed in this evaluation that all fuel oil consumed within the incineration system is consumed within the furnace.

At each of these facilities, a significant amount of the auxiliary fuel consumed in the furnaces is used during start-up, cool-down, and hot stand-by periods. However, only the Metro facility records fuel consumption during these periods.

Energy Comparisons

To allow different forms of energy consumption to be compared on an equal basis, each form of energy must be converted to an equivalent unit. Throughout this evaluation, energy consumption is presented both in raw form (kWh of electricity; cubic feet of natural gas; gallons of fuel oil; pounds of steam) and on the basis of equivalent Btu value (British Thermal Units). This allows an equal comparison of various forms of energy consumption. The following conversion factors are used (9):

Fuel Oil - 138,000 Btu/gallon (38,500 kJ/L)

Natural Gas - 1,000 Btu/cubic foot (37,300 kJ/cubic meter)

Digester Gas - 600 Btu/cubic foot (22,400 kJ/cubic meter)

Electricity - 10,000 Btu/kWh (accounts for inefficiency of electrical generation process)

Steam - Metro: 1,481 Btu/pound (3265 Btu/kg) based upon plant records

Duffin Creek: 1,572 Btu/pound (3465 Btu/kg) at 260 psi; and 520° F.

FACILITY COMPARISONS

The preceding section shows that the results of an energy evaluation are heavily influenced by how energy inputs and outputs for the incineration system are defined. This section summarizes the results of the energy evaluation and presents the results in a format that allows comparison between the four facilities. The four facilities are compared on the following levels:

Level A - Compare the facilities on the basis of auxiliary fuel consumed within the furnaces only. For the purposes of this evaluation, auxiliary fuel is expressed in terms of equivalent gallons (liters) of fuel oil.

Level B - Same as Level A, except consider energy inputs to the waste heat/auxiliary boiler equipment, the emission control equipment, and the ash disposal system. Steam produced and utilized outside of the incineration system is considered an energy output from the Metro and Duffin facilities. Digester gas will be considered a free fuel source and therefore, will not be considered an energy input to the Duffin system.

Level C - Same as Level B, except that electricity for equipment is considered an energy input.

Level D - Same as Level C, but consider energy inputs to the sludge conditioning/dewatering system.

Level E - Same as Level D, but consider energy inputs to sludge thickening or digestion. Auxiliary fuel, electricity for equipment, and electricity for general building requirements are considered energy inputs.

In all cases, auxiliary fuel consumption refers to the consumption of fuel oil and natural gas. Digester gas used by the Duffin Creek incineration system is not considered an energy input in this evaluation. The free use of digester gas as a fuel source compensates the Duffin Creek incineration system for the loss of sludge volatiles resulting from the digestion process. If digester gas were considered an energy input, this would add about 38,000 million Btu to the total Duffin Creek energy input for each case.

The energy inputs and outputs for each alternative are summarized on Table 9.

Table 10 presents estimates of fuel use for the Level A analysis. Fuel use for furnace startup and shutdown varied considerably, as follows:

Upper Blackstone	3 percent
Metro	35 percent
Duffin Creek	0
Cranston	not available

The value for Upper Blackstone is estimated by the plant staff. Because short-term shutdowns do not require auxiliary fuel in a fluidized bed system, fuel use for start-up at Duffin Creek is assumed to be 0. Although no data are available for Cranston, it is certain that most of the total fuel consumption is due to the intermittent operation schedule and frequent maintenance shutdowns.

For the Level A analysis (examining fuel use in the furnaces only), the Upper Blackstone, Metro, and Duffin facilities all fall within the fairly narrow range of fuel consumption of 7.4 to 8.6 gallons/dry ton (28 to 36 liters/dry tonne) with the Metro facility having the lowest fuel consumption under normal operating conditions. Note that each of the four facilities must use some auxiliary fuel at times to maintain steady-state burn conditions.

TABLE 9

ENERGY INPUTS AND OUTPUTS FOR LEVELS EVALUATED

	LEVEL				
ENERGY FORM	A	B	C	D	E
INPUTS					
AUXILIARY FEED IN FURNACE	X	X	X	X	X
ELECTRICITY TO FURNACE			X	X	X
ELECTRICITY TO DEWATERING				X	X
ADD OTHER PROCESSES AND BUILDING ELECTRICITY					X
OUTPUTS					
STEAM		X	X	X	X

TABLE 10

ESTIMATE OF ENERGY REQUIREMENT FOR LEVEL A
(MILLION Btu/YEAR)

ENERGY FORM	UPPER BLACKSTONE	METRO	DUFFIN CREEK	CRANSTON
Energy Input				
Natural Gas	6,800	68,400		35,000
Fuel Oil	4,400		11,700	
Total	11,200	68,400	11,700	35,000
Equivalent Gallons of Fuel Oil/Dry Ton	7.4	7.7	8.6	76.4

NOTE: Unless otherwise noted, all figures are based on 1987/1988 plant records.

Gallons = 3.785 L
Ton = 0.9072 tonne

Table 11 presents the estimated fuel use for the Level B analysis. In Level B, fuel used in the furnace and the waste-heat/auxiliary boiler equipment is considered an energy input, and steam and electricity produced by incineration and used outside the incineration system, which includes heat conditioning, are considered energy output.

This scenario shows that if only fuel oil and natural gas are considered energy inputs to the incineration system (including auxiliary boiler system) and credit is taken for steam production, the Metro incineration system is a net energy producer and the Duffin Creek incineration system comes very close to meeting this goal.

Table 12 presents the estimated fuel use for the Level C analysis. For Level C, electricity is considered an energy input to the furnace and the waste-heat/auxiliary boiler equiment, as well as fuel. Steam and electricity produced by incineration and used outside the incineration system, which system includes heat conditioning, are considered energy output.

Under this scenario, none of the four facilities qualifies as a net energy producer, although the Metro and Duffin Creek facilities approach this goal.

Table 13 presents the estimated fuel use for the Level D analysis. Level D considers energy inputs to sludge conditioning and dewatering, incineration, and the waste-heat/auxiliary boiler equipment. Steam and electricity produced by incineration and used outside the incineration system are taken as energy output. This level is the same as the definition used by the EPA construction grant program for "self-sustaining" incineration.

Under this scenario, net energy consumption increases significantly for each facility. None of the four facilities can be considered a net energy producer.

TABLE 11

ESTIMATE OF ENERGY REQUIREMENT FOR LEVEL B
(MILLION Btu/YEAR)

ENERGY FORM	UPPER BLACKSTONE	METRO	DUFFIN CREEK	CRANSTON
Energy Input				
Natural Gas	6,800	304,400	51,700	35,000
Fuel Oil	4,400		11,700	
Total	11,200	304,400	63,400	35,000
Energy Output				
Steam		305,500	61,000	
Electricity		22,100		
Total	0	327,600	61,000	0
Net Comparison	11,200	-23,200	2,400	35,000
Equivalent Gallons of Fuel Oil/Dry Ton	7.4	-2.6	1.8	76.4

NOTE: All figures are based on 1987/1988 plant records.

Gallons = 3.785 L
Ton = 0.9072 tonne

TABLE 12

ESTIMATE OF ENERGY REQUIREMENT FOR LEVEL C
(MILLION Btu/YEAR)

ENERGY FORM	UPPER BLACKSTONE	METRO	DUFFIN CREEK	CRANSTON
Energy Input				
Natural Gas	6,800	304,400	51,700	35,000
Fuel Oil	4,400		11,700	
Electricity to Furnace	18,000	30,000	6,500	9,000
Total	29,200	334,400	69,900	44,000
Energy Output				
Steam		305,500	61,000	
Electricity		22,100		
Total	0	327,600	61,000	0
Net Comparison	29,200	6,800	8,900	44,000
Equivalent Gallons of Fuel Oil/Dry Ton	19.3	0.8	6.6	96.0

NOTE: All figures are based on 1987/1988 plant records.

Gallons = 3.785 L
Ton = 0.9072 tonne

TABLE 13

ESTIMATE OF ENERGY REQUIREMENT FOR LEVEL D
(MILLION Btu/YEAR)

ENERGY FORM	UPPER BLACKSTONE	METRO	DUFFIN CREEK	CRANSTON
Energy Input				
Natural Gas	6,800	304,400	51,700	35,000
Fuel Oil	4,400		11,700	
Electricity for furnace	18,000	30,000	6,500	9,000
Electricity for conditioning/ dewatering	1,600	76,000	3,300	2,200
TOTAL	30,800	410,400	73,200	46,200
Energy Output				
Steam		305,500	61,000	
Electricity		22,100		
Total	0	327,600	61,000	0
Net Comparison	30,800	82,800	12,200	46,200
Equivalent Gallons of Fuel Oil/Dry Ton	20.3	9.3	9.0	100.8

NOTE: All figures are based on 1987/1988 plant records.

Gallons = 3.785 L
Ton = 0.9072 tonne

Table 14 shows the energy requirements for Level E In this analysis, the energy inputs include all fuel and electricity requirements from sludge pumping through incineration, including waste-heat and auxiliary boiler equipment and electricity for general building requirements. Steam and electricity produced by incineration and used outside the incineration system are taken as energy output.

This alternative shows a wide range of energy consumption figures for each unit process, reflecting the variety of technologies employed by the four facilities. The total energy conumption by the Upper Blackstone, Metro, and Duffin Creek solids handling trains ranges from 5.3 to 8.2 million Btu per dry ton (5.8 to 9.0 million Btu per dry tonne) of sludge cake processed.

Energy consumption at the Cranston facility is significantly higher, primarily due to the auxiliary fuel consumption by the incineration system.

Based on these figures, a reasonable estimate of total energy consumption by an energy-efficient solids handling train employing sludge incineration would be 5 to 9 million Btu per dry ton (5.8 to 10.4 million kJ per dry tonne) of sludge cake processed.

SUMMARY

Based upon this evaluation, the following generaliziations can be made regarding the energy consumption of a well-operated sludge incineration facility.

- Annual auxiliary fuel consumption within the furnace (Level A) should be in the range of 7 to 9 gallons of fuel per dry ton (29 to 38 liters/tonne) of sludge cake processed.

TABLE 14
ESTIMATE OF ENERGY REQUIREMENT FOR LEVEL E
(Btu/dry ton)

ENERGY FORM	UPPER BLACKSTONE	METRO	DUFFIN CREEK	CRANSTON
Energy Input				
Natural Gas	620,000	4,700,000	5,270,000	10,540,000
Fuel Oil	400,000	0	1,190,000	0
Electricity for sludge pumping	20,000	610,000	20,000	30,000
Electricity for thickening	1,050,000	1,420,000	0	2,300,000
Electricity for blending & mixing	10,000	0	0	90,000
Electricity for digestion	0	0	1,480,000	0
Electricity for storage	0	440,000	20,000	0
Electricity for conditioning/ dewatering	1,100,000	1,890,000	1,190,000	3,350,000
Electricity for sidestream treatment	0	420,000	0	0
Electricity for combustion	3,040,000	3,730,000	2,300,000	5,610,000
TOTAL	6,240,000	13,210,000	11,460,000	21,920,000
Energy Output				
Steam	0	4,720,000	6,210,000	0
Electricity	0	340,000	0	0
TOTAL	0	5,060,000	6,210,000	-
Net Comparison	6,240,000	8,150,000	5,250,000	21,920,000
Equivalent Gallons of Fuel Oil/Dry Ton	45	59	38	159

NOTE: All figures are based on 1987/1988 plant records.

Gallons = 3.785 L

Ton = 0.9072 tonne

- If a waste heat recovery system is included in the incineration system, the incineration system can be a net energy producer if only auxiliary fuel (no electricity) is considered an energy input to the system (Level B).

- If both auxiliary fuel and electricity are considered energy inputs to the incineration system, (Level C), an incineration system with a waste heat recovery system may still be a net energy producer if operating at maximum efficiency. Under these conditions, the Metro and Duffin Creek facilities approach the goal of being a net producer at their current loading rates. It is possible that, if these facilities were operating at capacity, the increase in energy efficiency that results from complete equipment utilization may make the Duffin Creek and Metro facilities net energy producers under these conditions.

- If the definition of the incineration system is expanded to include the sludge conditioning/dewatering system (Level D), the goal of net energy production by the incineration system does not appear achievable.

- Total energy consumption for a solids train utilizing sludge incineration can vary widely depending on the thickening and dewatering technologies utilized. Based on the results of this evaluation, total energy consumption for an energy efficient solids train may range from 5 million to 9 million Btu per dry ton (5.8 million to 10.4 million kJ per dry tonne) of sludge cake processed.

- Overall, the evaluation demonstrates that a variety of technologies can achieve energy-efficient sludge incineration. The most complex systems (Metro and Duffin Creek) proved to be very energy-efficient under each set of conditions evaluated. The simplest system (Upper Blackstone) also proved to be very energy efficient, especially in terms of overall energy consumption by the entire solids train (Level E).

REFERENCES

1. Proctor & Redfern Group, "Development of a Methodology To Investigate The Cost-Effectiveness of Various Sludge Management Systems", prepared for the Department of Supply and Services Canada, January 1988.

2. U.S. Environmental Protection Agency, "Improving Design and Operation of Multiple-Hearth and Fluid Bed Sludge Incinerators", July 1986.

3. Draft Regulatory Impact Analysis of the Proposed Regulation for Sewage Sludge Use and Disposal, November 1988.

4. U.S. Environmental Protection Agency, "Energy Conservation in Municipal Wastewater Treatment" EPA Contract No. 68-03-2186, Task 9, March 1978.

5. Water Pollution Control Federation, "Energy Conservation in the Design and Operation of Wastewater Treatment Facilities; Manual of Practice FD-2", 1982.

6. Environmental Protection Agency, "Estimating Sludge Management Costs", October 1985.

7. Environmental Protection Agency, "Sludge Treatment and Disposal", September 1979.

8. U.S. Environmental Protection Agency office of Water Programs Operations (WH-546), "Construction Grants 1985 (CG-85)", EPA Report No. 430/9-84-004, July 1984.

9. William F. Owen, "Energy in Wastewater Treatment", Prentice-Hall, Inc., New Jersey, 1982.

APPENDIX A

METROPOLITAN WATER POLLUTION CONTROL FACILITY

I. GENERAL INFORMATION

Address:
Metropolitan Wastewater Treatment Plant
2400 Childs Road
St. Paul, MN 55106

Phone Number: (612) 772-7222

Contact:
Nadim Shamat
Process Engineer
Sludge Processing & Incineration

Consultant:
Toltz, King, Duvall, Anderson & Assoc., Inc.
St. Paul, MN
Walter Thorpe, Project Engineer

Year Began Operation:
Original plant - 1938
Latest upgrade - 1978 to 1983

Design Average Flow:
Primary System 250 mgd
Secondary System 250 mgd

Design Peak Flow (Max Day):
Primary System 655 mgd
Secondary System 375 mgd

1987 Average Flow: 201 MGD

1987 Max Day Flow: approximately 700 MGD

1987 Average Influent CBOD: 198 mg/l

1987 Average Influent TSS: 190 mg/l

1987 Average Effluent CBOD: 11 mg/l

1987 Average Effluent TSS: 12 mg/l

Permitted Effluent CBOD:
October to May 24 mg/l
June to September 18 mg/l

Permitted Effluent TSS: 30 mg/l

Plant Overview:

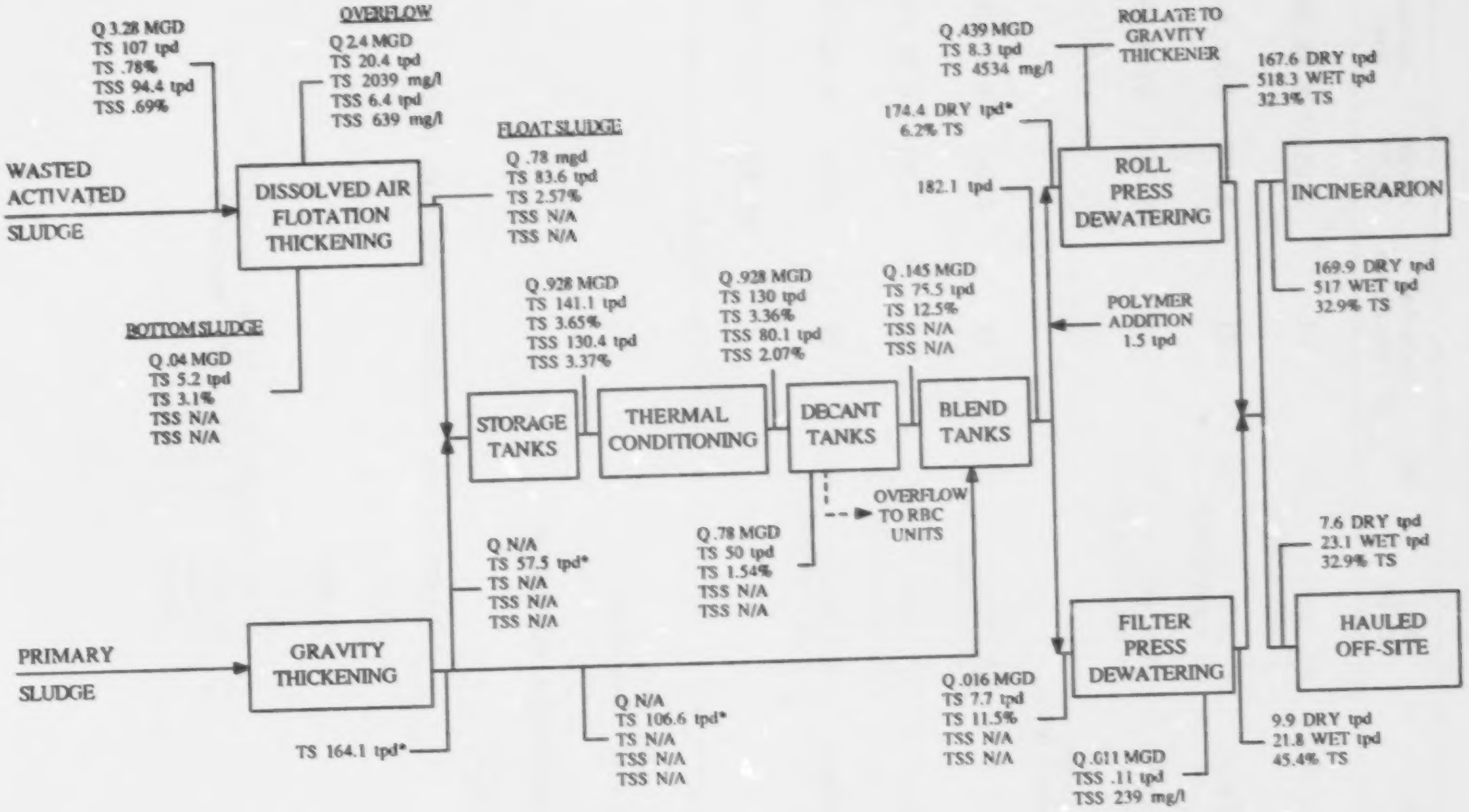
The liquid treatment train includes screening, aerated grit removal, primary settling, biological secondary treatment, final settling, chlorination, and dechlorination prior to discharge to the Mississippi River. Solids handling processes include flotation thickening of waste activated sludge, gravity thickening of primary sludge, separate storage of thickened waste activated sludge (TWAS) and thickened primary sludge, thermal conditioning of the thickened sludge, sludge dewatering using roll presses, sludge incineration, and ash disposal by landfilling. A small amount of sludge is hauled off-site for disposal. Diaphragm filter presses and vacuum filters are also available for sludge dewatering. At this time, the roll presses are the primary dewatering equipment and the vacuum filters and filter presses serve as backup units.

A schematic of the solids handling system is attached. Sludge quantities presented in this schematic are based on 1987 plant operating data. These quantities are taken directly from plant operating records. For some unit processes, there is a minor discrepency between the total input quantities and the total output quantities. These minor discrepencies are attributed to sampling variations.

II. UNIT COSTS

ITEM	UNIT COST
Labor ($/hour) *	$18.00 (operations) $22.00 (maintenance)
Polymer ($/#)	$.048/wet # $.658/dry #
City Water ($/100 gal)	$.37/100 gal
Electricity ($/kw-hr)	$.037/kw-hr
No. 2 Fuel Oil ($/gal)	$.90/gal
Natural Gas ($/100 cf)	$2.50/1000 cf
Chlorine ($/ton)	$177.63/ton

* Includes benefits


Q 3.28 MGD
TS 107 tpd
TS .78%
TSS 94.4 tpd
TSS .69%
WASTED
ACTIVATED
SLUDGE
OVERFLOW
Q 2.4 MGD
TS 20.4 tpd
TS 2039 mg/l
TSS 6.4 tpd
TSS 639 mg/l
DISSOLVED AIR
FLOTATION
THICKENING
BOTTOM SLUDGE
Q .04 MGD
TS 5.2 tpd
TS 3.1%
TSS N/A
TSS N/A
FLOAT SLUDGE
Q .78 mgd
TS 83.6 tpd
TS 2.57%
TSS N/A
TSS N/A
Q .928 MGD
TS 141.1 tpd
TS 3.65%
TSS 130.4 tpd
TSS 3.37%
STORAGE
TANKS
THERMAL
CONDITIONING
Q .928 MGD
TS 130 tpd
TS 3.36%
TSS 80.1 tpd
TSS 2.07%
DECANT
TANKS
OVERFLOW
TO RBC
UNITS
Q .78 MGD
TS 50 tpd
TS 1.54%
TSS N/A
TSS N/A
Q .145 MGD
TS 75.5 tpd
TS 12.5%
TSS N/A
TSS N/A
BLEND
TANKS
PRIMARY
SLUDGE
GRAVITY
THICKENING
TS 164.1 tpd*
Q N/A
TS 57.5 tpd*
TS N/A
TSS N/A
TSS N/A
Q N/A
TS 106.6 tpd*
TS N/A
TSS N/A
TSS N/A
Q .439 MGD
TS 8.3 tpd
TS 4534 mg/l
ROLLATE TO
GRAVITY
THICKENER
174.4 DRY tpd*
6.2% TS
182.1 tpd
ROLL
PRESS
DEWATERING
POLYMER
ADDITION
1.5 tpd
FILTER
PRESS
DEWATERING
Q .016 MGD
TS 7.7 tpd
TS 11.5%
TSS N/A
TSS N/A
Q .011 MGD
TSS .11 tpd
TSS 239 mg/l
167.6 DRY tpd
518.3 WET tpd
32.3% TS
INCINERARION
169.9 DRY tpd
517 WET tpd
32.9% TS
7.6 DRY tpd
23.1 WET tpd
32.9% TS
HAULED
OFF-SITE
9.9 DRY tpd
21.8 WET tpd
45.4% TS

NOTE: ALL FIGURES BASED ON 1987
PLANT OPERATING RECORDS
UNLESS NOTED WITH AN *

* REPRESENTS A CALCULATED FIGURE

Metro WPCF Solids Handling Schematic

III. SLUDGE TRANSFER PUMPING

Transfer Pump	No. Units	HP	Hours/Day Of Operation	KW-HR/ Day**	Annual Cost
Waste Activated Sludge to Thickening	10 total 2 operating*	75	24	2,685	$ 36,300
Primary Sludge Pumps to Thickening	22 total 6 operating*	75	24	8,056	$108,800
Sludge Transfer Pumps to Holding Tanks	20 total 8 operating*	75	24	10,742	$145,100
Sludge Transfer Pumps to Thermal Conditioning					
- to reactor	14 total 5.7 operating*	20	24	2,041	$ 27,600
- to decant tanks	12 total 3.8 operating*	60	24	4,082	$ 55,100
Sludge Transfer Pumps to Dewatering	8 total 2.3 operating*	30	24	1,235	$ 16,700
TOTAL				28,840	$389,600

* Under average conditions
** Based on connected horsepower

IV. WASTE ACTIVATED SLUDGE THICKENING

1. GENERAL INFORMATION

Technology:	Dissolved Air Flotation Thickeners (DAF)
Date Installed:	1979
Manufacturer:	Eimco
No. of Units:	16 under average conditions, operate: annual 9 units (1987 records) summer 8 units winter 16 units

2. Design Information

Unit Diameter (feet): 55 feet

Sidewater Depth (feet): 10 feet

Unit Surface Area (square feet): 2,250

Total Surface Area (square feet): 36,000

Solids Loading Rate (psf/day): 18 #/sf-day

Air:Solids Ratio: .02 - .04

Unit Capacity (dry tpd): 20

3. Operating Information (Based on 1987 records)

WAS to Thickening: 3.28 mgd
0.69% TSS
94.4 tpd TSS
0.78% Total Solids
107 tpd TS

Note that the DAF influent includes the waste sludge from the RBC sidestream treatment system.

Average Loading Rate (psf/day): 10.8 # TS/sf-day
9.3 # TSS/sf-day

Typical Sludge Volume Index (SVI): 150

Average Pressurized Effluent Recycle Flow: 15.6 mgd

Hydraulic Loading:

W.A.S. Feed	243 gpm/unit	(3.28 mgd total)
Recycled Effluent	1179 gpm/unit	(15.62 mgd total)
Total	1422 gpm/unit	(18.9 mgd total)

Average Hydraulic Loading (sludge + recycle): 960 gal/sf-day

Air Pressure (psig): 74 psig

Air Flow (cfm): 20,000 cfm/unit

Air to Solids Ratio (# air/# solids): average .044

Typical depth of Sludge Blanket: 30 inches

Chemical Addition (type & amount): Have ability to add polymer, but are currently not adding any chemical.

Solids Capture: 93%

Process Output:

Overflow Stream	2.4 mgd 639 mg/l TSS 6.4 tpd TSS 2039 mg/l TS 20.4 tpd TS

Overflow stream can be used as dilution (cooling) water for the Zimpro sidestream, returned to the gravity thickeners, or added to the secondary influent stream.

Float Sludge	0.78 mgd 2.6 % TS 83.6 tpd TS

Float sludge is pumped to the sludge storage or holding tanks.

Bottom Sludge	0.04 mgd 3.1 % TS 5.2 tpd TS

Bottom sludge is pumped to the gravity thickeners.

4. COST INFORMATION

A. Capital

Facility Planning Estimate of Construction Cost: $13,277,000

This cost was taken from the Toltz, King, Duvall, Anderson, & Assoc. Inc. study entitled Sludge Processing And Disposal At The Metropolitan Wastewater Treatment Plant, Volume II, January 1974. This cost is indexed at an ENR of 2100. If updated to September 1988 ENR of 4535, the estimated construction cost would be $28,670,000.

Actual Capital Cost (bid + change orders):

Facilities were constructed from 1978 to 1982 at a cost of $14,079,900. Costs updated to September 1988 ENR of 4535 are as follows:

equipment	$ 4,150,500
structural	$ 15,828,400
Total	$ 19,978,900

These costs includes the installation of 16 DAF thickeners, construction of thickener galleries and service areas, pipe tunnels, and installation of appurtenances such as chemical, electrical, HVAC, and odor control systems. For additional project description, see the appended advertisement for bids for Project No. 400. (Note that Project No. 400 includes construction of an RBC return liquor treatment facility. This cost has been broken out and included in Section XIII of this report.)

B. O&M (Based on 1987 operations & maintenance expense reports)

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	47.1 hr/day	$ 309,300
Maintenance Labor	46.6 hr/day	$ 373,800
Electricity	8,318,000 kw-hr/year	$ 323,700
Chemicals	None	
Contracted Services (maintenance)		$ 3,500
Materials & Supplies		
- operations		$ 100,700
- maintenance		$ 139,700
Total		$1,250,700

Note that the DAF thickener area and the RBC sidestream treatment system share an odor control system. The O&M costs for this odor control system are split between the DAF O&M costs presented above and the RBC O&M costs presented in Section XIII of this report. For further description of the odor control system, see Section XV of this report.

Facilities Planning Estimate Of Annual O&M Costs: $422,000

Taken from previously referenced Toltz, King, Duvall Anderson & Assoc. Inc. January 1974 study.

5. ENERGY CONSUMPTION

Equipment	No.	Units	Hr/Day	HP	KWH/Day*
Float/Underflow Sludge Collectors	16	total			
	13.5	operating	24	3	730
Float Sludge Draw Off Pump	8	operating	24	25	3,580
Underflow Sludge Draw Off Pump	16	total			
	13.5	operating	24	30	7,250
Overflow Return Pumps	3	total			
	1	operating	24	30	540
Polymer Feed Pumps	16	total			
	0	operating	—	—	—
Recycle Pumps	16	total			
	13.5	operating	24	100	24,170
Odor Control Equipment**				152	3,640
TOTAL					39,910

* Based on connected horsepower.
** For further information, see Section XV B of this report.

Electrical Requirements as Projected in Facilities Planning (kw-hr/yr):	Not available
Actual Annual Electrical Requirements (kw-hr/day):	39,910 based on connected horsepower 22,790 based on metered values

Note: The metered electrical use includes pumping of the thickened waste activated sludge to the sludge storage tanks.

V. GRAVITY THICKENING

1. GENERAL

Type of Sludge: Primary only

Thickener overflow is returned to the head of the plant or sent to the sidestream treatment unit (See Section XIV). Thickener underflow is pumped to the sludge holding or sludge storage tanks.

2. DESIGN INFORMATION

No. Tanks: 6

Diameter (feet): 65

Depth (feet): 10

Unit Surface Area (square feet): 3,300

Total Surface Area (square feet): 20,000

Solids Loading (psf/day): 20

3. OPERATING INFORMATION (Based on 1987 data)

Input Breakdown:

Primary Sludge	6.15 mgd 148.6 tpd TS
Rollate	0.44 mgd 8.2 tpd TS
Dilution Water	1.85 mgd 5.2 tpd TS
DAF Underflow	0.04 mgd 5.2 tpd TS
Total	8.5 mgd 167.2 tpd TS

Percent Solids of Sludge Feed: 0.47%

Average Loading Rate (#/sf/day): 17 # TS/sf/day

Peak Loading Rate (#/sf/day): 26 # TS/sf/day

Minimum Overflow Rate (gal/sf/day): 350 gal/sf/day

Average Overflow Rate (gal/sf/day): 430 gal/sf/day

Average Depth of Sludge Blanket: 4.7 feet

Odor Control: Chlorine addition (tanks are not covered)

Output Breakdown (1987 records):

Underflow	0.462 mgd 6.67 % TS 128.5 tpd TS

Overflow	8.0	mgd
	395	mg/l TSS
	13.2	tpd TSS
	1433	mg/l TS
	47.8	tpd TS

The values presented above are taken directly from the 1987 operation summary sheets. The plant staff reports that these figures are not accurate due to flow metering problems and difficulties obtaining a representative sample for solids analysis. For this reason, the figures presented above are not displayed in the solids handling schematic shown on page 3 of this report. Instead, the output from the gravity thickening process is calculated as follows (reference solids handling schematic for clarification):

1. Gravity thickened sludge that by-passes the thermal conditioning system.

Sludge feed to dewatering	182.1 tpd TS
Decant tank underflow	75.5 tpd TS
Gravity thickened sludge that by-passes the thermal conditioning system	106.6 tpd TS

2. Gravity thickened sludge that is fed to the thermal conditioning system.

Zimpro reactor feed	141.1 tpd TS
DAF thickener float sludge	83.6 tpd TS
Gravity thickened sludge fed to the thermal conditioning system	57.5 tpd TS

3. Total gravity thickened sludge underflow.

Sludge that by-passes the thermal conditioning system	106.6 tpd TS
Sludge feed to thermal conditioning system	57.5 tpd TS
Total gravity thickener underflow	164.1 tpd TS

4. COST

A. Capital

Facility Planning Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders):

The gravity thickeners were not part of the recent plant modifications. These units were part of the original treatment facility. Original capital costs for these older areas of the plant are not available. It is estimated that the gravity thickening facilities would have a construction cost of approximately $5,900,000 in 1988 dollars.

B. O&M (Based on 1987 operations and maintenance expense reports)

ITEM	CONSUMPTION LEVEL		ANNUAL COST
Operations Labor	757	hr/month	$ 163,500
Maintenance Labor	969	hr/month	$ 255,900
Chemical Addition (chlorine)	88	tons/year	$ 15,000
Plant Water	0	gpd	
Electricity	857,600	kw-hr/year*	$ 36,700
Contracted Services			
- operations			$ 7,900
- maintenance			$ 3,100
Materials & Supplies			
- operations			$ 8,800
- maintenance			$ 36,500
Total			$527,400

* The 1987 Region II (see subsequent below) Electrical Usage Summary Sheet showed a metered electrical usage of 643,200 kw-hr/year through October 1. This figure was projected for the entire 12 months to be 857,600 kw-hr/year (643,200/.75).

Note that for in-house organizational purposes, the Metro staff divides the solids handling processes into two regions as follows:

Region I - Flotation and gravity thickening, sludge storage, thermal conditioning, and sidestream treatment systems.

Region II - Dewatering, scum, and incineration systems.

5. ENERGY CONSUMPTION

Annual Electrical Requirements (kw-hr/yr): 857,600 kw-hr/year (metered)

Note: The metered electrical use includes pumping of the gravity thickened sludge to the sludge storage tanks.

VI. SLUDGE STORAGE TANKS

1. GENERAL INFORMATION

These tanks are designed such that thickened sludge from the DAF units and the gravity thickeners can be input to the tanks and the tanks can discharge to the dewatering process or to other sludge storage or holding tanks. Under normal operation, all the thickened waste activated sludge and a portion of the thickened primary sludge is input to these tanks and the tanks discharge to the thermal conditioning process (see process schematic on page 3). The tanks are covered and are air mixed.

2. DESIGN INFORMATION

No. Tanks: 8

Length (feet): 135

Width (feet): 30

Depth (feet): 25

Unit Volume (million gal): 0.75 mg

Total Volume (million gal): 6.0 mg

3. OPERATING INFORMATION

TWAS/Primary Sludge Ratio: The storage tanks typically receive all the TWAS and a portion of the thickened primary sludge. The 6 MGD capacity equals about 7 days of sludge storage.

4. COST INFORMATION

A. Capital

Facility Planning Estimate of Capital: $4,900,000

> This cost was taken from the Toltz, King, Duvall, Anderson, & Assoc. Inc. study entitled Sludge Processing And Disposal At The Metropolitan Wastewater Treatment Plant, Volume II, January 1974. This cost is indexed to an ENR of 2100. If updated to September 1988 ENR of 4535, the estimated construction cost would be $10,582,000.

Actual Capital Cost (bid + change orders):

> Included under Project No. 402. Reference Section VII of this report.

B. O&M (Based on 1987 operations & maintenance expense records)

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	50.9 hr/day	$ 334,300 *
Maintenance Labor	47.6 hr/day	$ 382,100 *
Chemical Additions (odor control)		$ 28,500
Electricity	2,864,000 kw-hr/year **	$ 110,200
Contracted Services (maintenance)		$ 700
Materials & Supplies		
- operations		$ 17,200
- maintenance		$ 32,300
Total		$ 905,300

* Note that the labor costs presented here are very high for a sludge storage facility. It is likely that some of the labor costs charged to the storage facility account should have actually been charged to other solids handling processes.

** This metered value was obtained from the 1987 Region II Electrical Usage Summary Sheet.

Facilities Planning Estimate Of Annual O&M Costs: $105,000

Taken from previously referenced Toltz, King, Duvall Anderson & Assoc. Inc. January 1974 study.

5. ENERGY CONSUMPTION

Rated HP of Air Compressors:	150
No. of Compressors:	10
Typical Hours of Operation:	24 hour/day
Annual Electrical Requirements (kW-hr/yr):	9,802,400 (calculated from connected load) 2,864,000 (metered)

VII. THERMAL CONDITIONING SYSTEM

1. GENERAL

Thickened waste activated sludge and a portion of the thickened primary sludge are thermally conditioned in a Zimpro system. Sludge flows through a grinder, low pressure pump, and then a high pressure pump before entering the heat exchanger and reactor portions of the thermal conditioning system. High pressure steam and air are added to the sludge in the thermal reactor. Conditioned sludge flows from the reactor into decant tanks, which act as gravity thickeners to conentrate the sludge. Decant tank overflow is treated at the RBC return liquor treatment system. The system's heat exchangers and reactors are washed with a dilute nitric acid after about 300 hours of operation.

2. DESIGN INFORMATION

No. Reactors:	8
Unit Capacity (gpm sludge):	175
Unit Capacity (dry tpd @ 4% TSS):	40
Reactor Detention Time:	15 minutes
No. Decant Tanks:	4
Diameter (feet):	60
Sidewater Depth (feet):	20
Heat Exchanger Material of Construction:	316 L Stainless Steel

3. OPERATIONAL INFORMATION (based on 1987 records)

Operating Temperature and Pressure:	375 F and 325 psi
Operating Flow:	average 3.8 units operating at 170 gpm sludge feed/unit
Reactor Input:	.928 mgd 33,685 mg/l TSS 130.4 tpd TSS 3.65 % TS 141.1 tpd TS 74.4 % volatile solids 42,640 mg/l COD pH 6.2

Reactor Output:	20,695 mg/l TSS 80.1 tpd TSS 3.36 % TS 130.0 tpd TS 72.6 % volatile solids 41,720 mg/l COD pH 5.0

Note that reactor input solids (141.1 tpd TS) do not equal reactor output solids (130.0 tpd TS). This minor discrepency (8.5%) is attributed to sampling variations.

Steam Input:

An average of 15,922 lb/hour of steam is fed to the thermal conditioning system. This equates to an average steam input of 4190 #/hour/reactor, or 8 gpm/reactor.

Solids Solubilized:	50.3 tpd
Decant Input:	0.928 mgd 20,695 mg/l TSS 80.1 tpd TSS 3.36 % TS 130.0 tpd TS 72.6 % volatile solids pH 5.0
Decant Output:	
Underflow	0.145 mgd 12.5 % TS 75.5 tpd TS 64.8 % volatile solids pH 5.4
Overflow	0.78 mgd 15,372 mg/l TS 50 tpd TS 8,424 mg/l BOD 27.4 tpd BOD 18,924 mg/l COD

Note that the decant input solids (130.0 tpd TS) do not equal reactor output solids (125.5 tpd TS). This minor discrepency (3.6%) is attributed to sampling variations.

4. COSTS

A. Capital

Facility Planning Estimate of Capital: $17,861,000

This cost was taken from the Toltz, King, Duvall, Anderson, & Assoc. Inc. study entitled Sludge Processing And Disposal At The Metropolitan

Wastewater Treatment Plant, Volume II, January 1974. This cost is indexed to an ENR of 2100. This cost estimate included the construction of the thermal conditioning building, the decant tanks, and the heat treatment equipment. If updated to September 1988 ENR of 4535, the estimated construction cost would be $38,600,000.

Actual Capital Cost (bid + change orders):

The building to house the thermal conditioning system was constructed from 1977 to 1982 at a cost of $16,397,900. This project (Project No. 402) included the construction of the thermal conditioning building (approximately 275 ft * 103 feet; 3 story), four decant tanks, eight sludge storage tanks, and a building to house appurtenances for the sludge storage system (approximately 275 ft * 35 ft; 2 story). The thermal conditioning system was installed from 1980 to 1983 at a cost of $12,282,500 (Project No. 401).

Total project costs updated to September 1988 ENR of 4535 breakdown as follows:

equipment	$ 10,972,000
structural	$ 26,400,000
Total	$ 37,372,000

For additional project description, see appended advertisement for bids for Project No. 401 and Project No. 402.

B. O&M (Based on 1987 operations & maintenance expense records)

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	178.4 hr/day	$ 1,172,000
Maintenance Labor	47.1 hr/day	$ 378,300
Chemicals (acid)		$ 22,700
Electricity	7,645,000 kw-hr/year*	$ 311,100
Contracted Services (maintenance)		$ 17,300
Materials & Supplies		
- operations		$ 34,600
- maintenance		$ 204,700
Total		$ 2,140,700

* This metered value was obtained from the 1987 Region II Electrical Usage Summary Sheet.

Note: The electrical cost for the sludge transfer pumping from the storage tanks to the thermal conditioning system is included in this table.

For odor control purposes, odorous off-gases from the reactor area and the decant tanks is used as combustion air in the MHF system. The electrical cost to convey this odorous air stream to the incineration system is included in the above table.

5. Energy

Equipment	HP	No. Units	Hrs/Day	KW-HR/Day
Sludge Grinders	2		163 (total)	240
Low Pressure Pumps	20	14 (6 standby)	163 (total)	2,440
High Pressure Pumps	60	12 (4 standby)	82 (total)	3,670
Process Air Compressors	125	10	82 (total)	7,650
Underflow Sludge Pumps	25	8	15 (total)	280
Decant Overflow Pumps	20	4	30 (total)	450
Scum Pumps	10	4	24 (total)	180
Total				14,900

Annual Electrical Requirements (kw-hr/yr): 5,438,500 (calculated)
7,645,000 (metered)

Note that the metered electrical usage exceeds the calculated electrical usage. This is because some sources of consumption such as the fans that transfer odorous off gases to the MHF system and the building lighting are not accounted for in the above table.

VIII. SLUDGE HOLDING TANKS

1. GENERAL INFORMATION

These tanks are designed to accept thickened sludge from the gravity thickeners, flotation thickeners, sludge storage tanks, or decant tanks and discharge sludge to the dewatering process or to sludge storage tanks. Under normal operation, these tanks receive a mixture of thermally conditioned sludge from the decant tanks and thickened primary sludge from the gravity thickeners. Air mixing is provided.

2. DESIGN INFORMATION

No. Tanks:	2
Length:	64 feet
Width:	36 feet
Sidewater Depth:	15 feet

Unit Volume:	0.26 mgd
Total Volume:	0.52 mgd

3. COST INFORMATION

A. Capital

Facility Planning Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders):

These tanks are part of the original vacuum filter sludge dewatering system. Original capital costs for these older areas of the plant are not available. It is estimated that the construction cost for these tanks would be approximately $100,000 in 1988 dollars.

B. O&M

Included in Section IX O&M costs.

4. ENERGY REQUIREMENTS

Equipment	No. Units	Hr/Day	HP	KHW/DAY *
Air Compressors	4	24	30	2,148

* Included in the metered electrical usage for sludge dewatering.

IX. SLUDGE DEWATERING

Note: Three dewatering technologies; roll presses, filter presses, and vacuum filters, are available at the Metro facility. In 1987, roll presses were used as the primary dewatering device. The vacuum filters were not operated for a significant period of time. The filter presses were operated for significant periods of time in the months of February, March, April, and May. Information and operating data for both the roll presses and filter presses will be presented here.

A. Roll Press Dewatering

1. GENERAL INFORMATION

Technology:	Roll Presses
Date Installed:	1982
Manufacturer:	Ingersoll-Rand

2. DESIGN INFORMATION

No. Presses:	4
Diameter (feet):	3
Length (feet):	10
Unit Capacity:	90 dry tpd
Feed Solids:	6%
Cake Solids:	35%
Solids Recovery:	95%
Polymer Dose:	5 to 10 lb/dry ton

3. OPERATING PARAMETERS (Based on 1987 operating data)

Sludge Feed:

In normal operation, a mixture of heat conditioned TWAS, heat conditioned primary sludge, and primary sludge that did not receive heat conditioning is fed to dewatering. At times, all of the sludge by-passes the heat conditioning system and goes directly to dewatering.

Average feed to Dewatering:

174.4 dry tpd (calculated)
6.2 % TS
69.0 % volatiles

Gravity Thickened Sludge/ Decant Ratio:

- By volume 3.1/1
- By Mass 1.6/1

Heat Value of Cake:	10,500 Btu/# VSS
Average No. Units In Service:	2.3
Polymer Type:	Nalco 7287
Polymer Dosage:	1987 average 18.1 dry #/ton

As the percent of thermally conditioned sludge increases, the polymer dosage increases.

Frequency of Testing to Optimize Polymer Dosage:

Operators adjust the polymer feed rate once per shift based on vat pressure.

Other Chemicals:

Capability to apply lime and ferric chloride exists, but is not necessary.

Cake Product (1987 data):

518.3 wet tpd
167.6 dry tpd
32.3 % solids
70 % volatiles

Solids Capture: 95.3%

Roll Pressure: Ranges 100 - 2000 lbs/linear inch

Sidestream Strength: .439 mgd
(Rollate) 4,533 mg/l TS
8.3 dry tpd

Odor Control:

Odorous gases from the dewatering area are conveyed to the incineration area and used as combustion air.

Historical data provides the following summary of roll press performance for various sludges.

	Heat-Treated And Primary Sludge	Primary Sludge
% Solids of Feed	6.2%	5.7%
% Solids of Cake	31.9%	31.4%
Polymer Dosage (dry #/dry ton solids)	19.0	8.9

4. COST INFORMATION

A. Capital

Facilities Planning Estimate of Capital: $4,993,000

This cost was taken from the Toltz, King, Duvall, Anderson, & Assoc. Inc. study entitled Sludge Processing And Disposal At The Metropolitan Wastewater Treatment Plant, Volume II, January 1974. The cost is indexed to an ENR of 2100. At the time of this report, the recommended plan was to expand and upgrade the existing vacuum filtration dewatering system. This cost estimate included 8 new vacuum filters, construction of an expansion to the dewatering building, and necessary electrical and mechanical work. If updated to September 1988 ENR of 4535, the estimated construction cost would be $10,780,000.

Actual Capital Cost:

The roll presses were installed in the original sludge dewatering building. Four vacuum filters were removed and replaced with four roll presses. Removal of the vacuum filters and preparation of the building for the roll presses was completed under Project No. 405 at an approximate cost of $172,000. Installation of the roll presses was performed under Project No. 404 at a cost of $3,685,900.

Total project costs updated to a September 1988 ENR of 4535 breakdown as follows:

equipment	$3,994,900
structural	$ 778,400
Total	$4,773,300

For additional project description, reference appended advertisement for bids for Project No. 404 and Project No. 405.

B. O&M (Based on 1987 operations and maintenance expense records)

ITEM	CONSUMPTION LEVEL		ANNUAL COST
Operations Labor	175.7	hr/day	$ 1,153,600
Maintenance Labor	75.2	hr/day	$ 603,700
Polymer	18.2	#/dry ton	$ 767,700
Other Chemicals (Lime)			$ 12,900
Electricity	4,600,000	kw-hr/year*	$ 169,200
Materials & Supplies			
- operations			$ 11,000
- maintenance			$ 74,500
Contracted Services			
- operations			$ 0
- maintenance			$ 4,800
Total			$ 2,797,400

* Based on projected values presented in the 1987 Region III Electrical Usage Summary Sheets.

Facilities Planning Estimate Of Annual O&M Costs: $612,000

Taken from previously referenced Toltz, King, Duvall Anderson & Assoc. Inc. January 1984 study.

5. ENERGY CONSUMPTION

Equipment	HP	NO. UNITS*	HRS/DAY	KW-HR/DAY
Roll Presses	60	2.3	24	2470
Sludge Feed Pumps	30	2.3	24	1235
Filtrate Pumps	20	1.5	24	540
Polymer Feed Pumps	2	2.3	24	80
Total				4325

* Have 4 of each piece of equipment available. This column shows the average number of units in operation in 1987.

Annual Electrical Requirements (kw-hr/year):

1,578,600 kw-hr/year (Based on connected horsepower)
4,600,000 kw-hr/year (Based on projections by plant staff)

Note that the metered electrical usage includes electricity used to convey the odorous gas stream to the incineration system for odor control purposes, building lighting, and other miscellaneous sources of consumption.

B. Filter Press Dewatering

1. GENERAL

The filter press units serve as a back-up technology to the roll presses. In 1987, the filter presses were operated for significant periods of time during the months of February, March, April, and May. All operating data presented in this section will be based on this demonstration period. During this period, the presses were used in conjunction with the roll presses. The filter presses were used exclusively to dewater thermally conditioned sludge rather than a thermally conditioned/gravity thickened mixture.

2. DESIGN INFORMATION

Type of Press:	Diaphragm type with a water-compressed diaphragm (Lasta)
No. Presses:	8
Filter Service Area Per Unit:	1,666 square feet
Plate Size (approximate):	1,500 mm * 1500 mm
Discharge Volume Per Press:	39 cubic feet

Cake Wet Density (approximate):	70 pounds/cubic foot
Cycle Time:	24 - 30 minutes
Unit Capacity (approximately):	30 dry tons per day
No. Surge Bins:	8
Surge Bin Capacity:	800 cf/unit

3. OPERATING PARAMETERS (Based on 1987 data)

Note: Because these units were only operated from February through May in 1987, "average" operating parameters will be presented in two ways: (1) an annual (365) day average; and (2) a four month (February to May) average.

Sludge Feed:	Thermally conditioned sludge

Average No. Units in Operation:

Four month average	1.5
Annual average	0.5

Average No. Press Cycles Per Day:

Four month average	54
Annual average	18

Feed Sludge

	Four Month Average	Annual Average
Flow	.047 mgd	.016 mgd
Total Solids	11.9 %	11.5 %
Total Solids	23.3 dry tpd	7.7 dry tpd

Sidestream (Pressate)

	Four Month Average	Annual Average
Flow	.03 mgd	.011 mgd
TSS	2878 mg/l	2398 mg/l
TSS	.36 dry tpd	.11 dry tpd
Total Solids	47 %	48 %
Volatile Solids	67.1 %	66.6 %

Sludge Cake

	Four Month Average	Annual Average
Wet Cake	65.98 tpd	21.8 tpd
Dry Cake	30.04 tpd	9.9 tpd
% Solids	45.5 %	45.5 %
Volatile Cake	20.55 tpd	6.8 tpd
% Volatiles	68.4 %	68.7 %

4. COST INFORMATION

A. Capital

Facilities Planning Estimate of Capital: See Section IX A.

Actual Construction Cost:

An addition to the existing dewatering building was constructed from 1977 to 1981 to house the filter press units (Project No. 406) at a cost of $12,800,700. The filter press units (8 units) were installed from 1980 to 1983 (Project No. 401) at an approximate cost of $4,094,200. Total project costs updated to a September 1988 ENR of 4535 breakdown as follows:

equipment	$ 2,882,700
structural	$ 14,435,600
Total	$ 17,318,300

For additional project description, reference the appended advertisement for bids for Project No. 401 and Project No. 405.

B. O&M

The filter presses were operated for such a short period of time in 1987 that good O&M cost information could not be obtained. Cost information obtained from this short testing period would not be representative of a full year of operation.

X. GRIT, SCREENINGS, AND SCUM DISPOSAL

GRIT DISPOSAL: Landfilled

SCREENINGS DISPOSAL: Landfilled

SCUM AND GREASE DISPOSAL:

Scum is pumped from the primary tanks to 3 skimming tanks where it is separated from the transport water. Scum is decanted and heated in a decant hopper. Decanted scum is pumped at 1500 gal/hour to preparatory units where the incinerator feed pumps are located. The preparartory system includes "Muffin Monster" maceration prior to incineration. Each incinerator has 2 ports on the combustion hearth that can accept 60 to 100 gal/hour of scum. The scum temperature must be maintained at 180 F to 190 F as it passes through the transport system. Scum entering the furnace must be metered carefully to prevent wild temperature fluctuations within the furnace. Operator communication and tight control of the sludge feed and excessive air supply are necessary to maintain control of the furnace as sludge is pumped into the system. The decanted scum/grease heating value is about 15,000 Btu/liquid #.

XI. INCINERATION

1. GENERAL INFORMATION

Technology:	Multiple Hearth Incineration
Date Installed:	2 units in 1982 1 unit in 1972 3 units in 1968 1 unit in 1952 (retired) 3 units in 1938 (retired)
Manufacturer:	2 - 1982 units: BSP 3 - 1968 units: BSP (1 with heat recovery) 1 - 1972 unit : Nichols (with heat recovery)
No. of Units:	6 (2 of which are in reserve capacity)

Note: As part of the 1983 plant upgrade, 2 new units equipped with heat recovery were installed and 2 of the 4 existing units were refurbished and equipped with heat recovery.

Diameter: 22 feet

2. DESIGN INFORMATION

No. of Hearths Per Unit: 8 + 0 hearth afterburner

Note that no auxiliary fuel is generally used in the afterburner chamber. The cake feed by-passes the zero hearth. A large drophole allows the sludge to drop directly to HEARTH No. 1 Hearths No. 3 and 4 are double the normal hearth depth to insure complete combustion by providing additional mixing of the volatiles and combustion air at combustion temperatures.

Hearth Area Per Unit (excluding afterburner): 2,100 square feet

Wet Solids Loading:

- average	11 psf/hour
- maximum	15 psf/hour

Approximate Unit Capacity (30% to 45% cake solids):

- average	60 - 70 dry tpd
- maximum	80 - 90 dry tpd

Air Supply

- Combustion Air (max)	760 lb/min
- Cooling Air (max)	630 lb/min
- Excess Air Ratio (min)	75 %

Afterburner Data:

- temperature	1200 - 1400 F
- residence time	1.4 seconds

3. OPERATING PARAMETERS

Operation Schedule: 24 hr/day
7 day/week

Cake Feed (based on 1987 data):

Total Cake Produced On-Site:

Plate & Frame Filter Press Cake	9.9 dry tpd
Roll Press Cake	167.5 dry tpd
Vacuum Filter	0.1 dry tpd
Total	177.5 dry tpd
Cake Hauled Off-Site For Disposal *	7.6 dry tpd (23.1 wet tpd)
Cake To Incineration	169.9 dry tpd (517 wet tpd)

*In 1987, a small amount of cake was disposed of off-site to complete a three year agreement signed in 1985. This cake is lime stabilized and land applied at area farms. In 1985, there was still some question as to the ability of the incineration system to dispose of all of the Metro sludge 365 days per year. Therefore, the Metropolitan Sewer Board entered into a three year agreement to land apply some sludge at area farms as a safety valve in case of an emergency shutdown of the incineration system. During this three year period, the incineration system has demonstrated that it can handle all sludge production without requiring a reserve disposal option. As a result, the land application contract was not renewed and all sludge production was processed by the incineration system in 1988.

Average Loading Rate: 517 wet tpd total
2.53 dry ton/hour/unit
5060 dry #/hour/unit

The staff prefers to operate each furnace at about 75 percent capacity. This allows some excess capacity to provide a buffer against fluctuations in daily sludge production and to allow short term maintenance shutdowns.

Average Hours Of Operation: 66.9 hours/day

No. Units typically in Operation: 2.8 average

Speed of Rabble Arms: 50 rev per hour

Percent Excess Air: average 207% excess air
14% oxygen concentration in flue gas

Average Wet Solids Loading: 7.35 psf/hour

Average Volume of Shaft
Cooling Air Returned As Consumption Air: None

Total Air Feedrate: 22,000 to 23,000 cfm/incinerator

Air from the dewatering area, the sludge holding tanks, and the Zimpro decant tanks is used as combustion air in the furnaces. Typical air volumes are as follows:

Sludge holding tanks	6,000 cfm
Zimpro decant tanks	3,000 to 4,000 cfm
Dewatering Area	40,000 to 50,000 cfm

The plant staff is currently installing hoods over the dewatering equipment to capture the odorous gases emitted by the dewatering process. This will isolate the odorous gas stream from the building air supply, thereby significantly reducing the air volume which must be treated for odor control. This will significantly reduce the 40,000 to 50,000 cfm of air flow from the dewatering area that is currently used as combustion air in the incineration system. The reduction in air flow from the dewatering area will free up some air capacity in the incineration system and allow the plant staff to utilize odorous gases from other process areas (scum hoppers and holding tanks) as combustion air.

Temperature Profile of Incinerator (degrees F):

*	Hearth 0	1120
	Hearth 1	1140
*	Hearth 2	1450
	Hearth 3	1600
*	Hearth 4	1030
	Hearth 5	840
*	Hearth 6	500
*	Hearth 7	250
	Hearth 8	150

* These hearths have 2 burners/hearth.
All other hearths have no burners.

Ash Fusion Temperature: 1900 F

Operation Guidelines:

In a non-autogenous incineration system, the major operation control is the input of auxiliary fuel to maintain combustion temperatures. In an autogenous system such as the Metro system, the major operation control is the input of combustion air to the furnace. The furnace temperature profile is controlled by varying the combustion air supply. The air supply can be targeted for any hearth or any combination of hearths. Each furnace is loaded at about 75 percent capacity under average conditions to accomodate short term fluctuations in sludge production and to allow for the feeding of a drier sludge that would require more combustion/cooling air at the same wet loading rate. Operators strive to maintain a combustion hearth temperature of 1600 F to allow complete combustion and avoid the formation of clinkers.

Maintenance Schedule:

The Metro staff has implemented a very effective maintenance program aimed at discovering and correcting minor problems before they become major problems. Each month, the entire dewatering and incineration system is taken out of service for an intense 16 hour maintenance overhaul. All equipment and instrumentation are reviewed during these shutdowns. Once each year, the entire solids handling train is taken out of service at once for a more detailed maintenance inspection. This annual shutdown is scheduled for the summer months when sludge production is low. These shutdowns are possible because the solids handling system has been designed with a reasonable amount of sludge storage and excess capacity.

4. COST INFORMATION

A. Capital

Facilities Plan Estimate of Construction Cost: $6,444,000

This cost was taken from the Toltz, Duvall, Anderson, & Assoc. Inc. study entitled Sludge Processing And Disposal At The Metropolitan Wastewater Treatment Plant, Volume II, January 1974. This cost is indexed to an ENR of 2100. At the time this report was written, the recommended plan was to modify the existing furnaces by upgrading the air pollution control system and installing a heat recovery system. Installation of additional furnaces was not included in this cost estimate. If updated to September 1988 ENR of 4535, the estimated construction cost would be $13,920,000.

Actual Capital Cost (bid + change orders):

Additions and modifications to the incineration system were completed from 1978 to 1983 under Project No. 407 and Project No. 408. Under Project No. 408, an addition to the existing incineration building was constructed to house two new furnaces and new air pollution control and heat recovery systems. Modifications to the four existing furnaces was also completed under this project. Under Project No. 407, two new furnaces with air pollution control equipment and all necessary appurtenances were installed in the new building addition. Costs for these projects breakdown as follows:

PROJECT	ORIGINAL CONSTRUCTION COST	CONSTRUCTION COST UPDATED TO ENR=4535
Project No. 408		
- building addition	$ 88,755,300	$ 92,759,900
- furnace modifications	$ 4,000,000	$ 5,791,800
Project No. 407		
- furnace installation	$ 10,313,400	$ 24,984,500
TOTAL	$ 103,068,700	$ 123,536,200

Total project costs breakdown as follows (ENR 4535):

equipment	$ 30,776,300
structural	$ 92,759,900
Total	$ 123,536,200

For further project description, reference the appended advertisement for bids for Project No. 407 and Project No. 408.

B. O&M (Based on 1987 operations and maintenance expense reports)

O&M costs for the incineration system and the boiler system (waste heat recovery and auxiliary boilers) will be presented separately so that fuel use by the furnaces and fuel use by the boilers can be differentiated.

Furnace O&M Costs

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	304 hr/day	$ 1,998,500
Maintenance Labor	286.5 hr/day	$ 2,300,800
Natural Gas	68,359,000 cf/year *	$ 129,900
No. 2 Fuel Oil	None	
Chemicals	None	
Electricity	18,139,700 kw-hr/year**	$ 679,300
Contracted Services		
- operations		$ 3,200
- maintenance		$ 101,200
Materials & Supplies		
- operations		$ 46,500
- maintenance		$ 511,500
TOTAL		$ 5,770,900

* Taken from 1987 incineration process annual summary sheets

** 1987 Region III Electrical Summary Sheets show an electrical use of 13,604,250 kw-hr through October 1, 1987. This figure was projected for 12 months to obtain an estimated annual use of 18,139,000 kw-hr/year (13,604,250 /.75).

Boiler O&M Costs

ITEM	CONSUMPTION LEVEL		ANNUAL COST
Operations Labor	163	hr/day	$ 1,073,200
Maintenance Labor		hr/day	$ 0
Natural Gas	236,064,500	cf/year	$ 627,400
No. 2 Fuel Oil	None		
Water			$ 14,900
Chemicals (boiler feedwater)			$ 55,500
Electricity	6,046,300	kw-hr/year*	$ 223,700
Contracted Services			
- operations			$ 800
- maintenance			$ 8,800
Materials & Supplies			
- operations			$ 71,600
- maintenance			$ 64,700
TOTAL			$ 2,140,600
Steam "Sales" to Other Plant Areas **			$ 696,300
NET COST			$ 1,444,300

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* 1987 Region III Electrical Summary Sheets show an electrical use of 4,534,750 through October 1, 1987. The figure was projected for 12 months to obtain an estimated annual use of 6,046,300 kw-hr/year (4,534,750/.75).

** Heat is recovered from the incineration process utilizing a waste heat boiler and an additional economizer section that increases the energy recovery efficiency from 33.5% to about 40%. Most of the recovered heat is utilized by the Zimpro thermal conditioning process. Excess steam production is utilized to provide building heat and drive steam turbines. This excess steam produced by the incineration process should be considered an energy and cost credit. See Section XI for a detailed breakdown of steam use.

5. ENERGY CONSUMPTION

Information requested here pertains to the four lead furnaces.

Equipment	No. Units	Rated HP	Hrs/day Operation	kw-hr/day *
Stack Jacket Ambient Air Fans	4	30	0	0
Plant Water for Scrubber				31,670
Induced Draft Fan **	4	500	24	35,800
Slurry Pump			0	0
Ash Vacuum Pump	3	125	24	6,710
Shaft Cooling Air Fan	4	30	24	2,150
Primary Combustion Air Fan	4	40	—	—
Secondary Combustion Air Fan	4	150	24	10,740
Shaft Drive	4	10	24	720
Conveyors	10	1	24	180
Total				87,970

* Based on connected horsepower

** The induced draft fans are driven by a steam turbine when excess steam is available. This partially offsets the electrical consumption by this equipment.

Furnace Annual Electrical Requirements (kw-hr/year):

Based on connected horsepower: 22,476,300 for 2.8 units
Based on metered values: 18,139,000

Annual Fuel Use:

	No. 2 Fuel Oil gal/dry ton	Natural Gas cubic feet/dry ton	Equivelent Fuel Oil * gal/dry ton
1984	0	654	4.7
1985	438	544	3.9
1986	9	655	4.7
1987	0	1102	7.6

* Total fuel consumption (fuel oil and natural gas) expressed as gal/dry ton of No. 2 fuel oil.

The previous table reflects fuel consumption for the furnaces only. This does not include consumption be the auxiliary boiler system. This table does include fuel consumed during furnace start-up and cool-down periods.

Note that fuel use increased significantly in FY 1987. This increase is attributed to a requirement for a zero hearth temperature of 1000 F that went into effect in 1986.

Annual Fuel Use For Start-up and Cool-Down Periods (cf/year):

Natural Gas	23,134,000 cf/year	(373 cf/dry ton)
Fuel Oil	0 gal/year	

Annual fuel Use For Auxiliary Boiler System:

	Natural Gas (cf/year)	Fuel Oil (gal/year)
Auxiliary Boiler No. 1	100,387,900	0
Auxiliary Boiler No. 2	135,676,600	0
Total	236,064,500	0

6. ENERGY RECOVERY

Technology:

Waste heat boilers with economizer sections. These WHB units are tube type exchangers with an upper and lower drum ("o" type boiler).

Waste Heat Boilers:

No. Units	4
Normal Pressure Drop	1.5" w.c.
Inlet Temperature	1000 - 1400 F
Outlet Temperature	500 - 600 F
Capacity	17,000 lb/hr

Economizer:

Normal Pressure Drop	1.0" w.c.
Outlet Temperature	400 - 500 F
Capacity	17,000 lb/hr

Energy Recovery Efficiency:

without economizer section	33.5%
with economizer section	40%

Auxiliary Boilers:

No. Units	2
Capacity	70,000 lb/hr

Steam Production:

	Annual Production (#/Year)	Average Hourly Production (#/Year)
Auxiliary Boiler No. 1	78,449,600	8,955
Auxiliary Boiler No. 2	113,407,300	12,945
Subtotal	191,856,800	21,900
Waste Heat Boiler	245,639,900	28,040
Total Steam Production	437,496,800	49,940

Steam Pressure: 425 psi

Steam Use:

Steam pressure is reduced to lower pressures prior to use in plant processes or for plant heating. Steam use is prioritized as follows:

First Priority - Provide 100% of required Zimpro steam.

Second Priority - Drive steam turbines for ID fans, water pumps, and auxiliary boilers. This reduces steam pressure from 425 psi to 125 psi.

Third Priority - Provide 100% of plant heating requirements. Steam used to drive the ID fans is used a second time to provide building heat. This reduces steam pressure from 125 psi to 15 psi.

Enough steam is always available to meet the needs of the Zimpro process. If extra steam is available, second and third priority demands are also met.

Steam Utilization:

Note that some steam is used twice, once to drive steam turbines and a second time for building heat (HVAC). Both uses will be detailed in these tables.

1. Steam Turbines (reduces steam pressure from 425 psi to 125 psi)

Steam Turbine	Operation Hours	Electrical Cost Savings
* Incinerator Turbines (Induced Draft Fans)		
Unit No. 7	1588	$190,500
Unit No. 8	807	$ 21,700
Unit No. 9	240	$ 2,900
Unit No. 10	38	$ 500
Subtotal	2673	$215,600
* Boiler Feedwater Turbines		
Unit CP24	343	$ 1,000
Unit CP25	316	$ 1,000
Unit CP26	2218	$ 6,700
Unit CP27	4000	$ 12,000
Unit CP28	1853	$ 5,600
Subtotal	8730	$ 26,300

* Auxiliary Boiler Turbines		
Unit No. 1	594	$ 17,800
Unit No. 2	151	$ 9,500
Subtotal	745	$ 27,300
** Misc. Turbines	16,165	$ 81 600
TOTAL	28,313	$350,600

* These processes are directly part of the incineration/steam generation process and therefore are considered a system operating cost. No cost credit to the incineration/heat recovery system can be claimed for these uses.

** These steam uses are external to the incineration/steam generation system, therefore a cost credit can be taken for these uses.

2. Process Use

Process	Annual Steam Use (#/year)	Average Hourly Steam Use (#/hour)	Dollar Value Of Steam ***
** Chlorination System	319,420	36	$ 1,000
* Thermal Conditioning	139,476,100	15,922	$415,600
* Boiler Feedwater Prep.	42,336,000	4,833	$126,200
** HVAC (Building Heat)	205,952,700	23,510	$613,700
Total	388,084,200	44,301	$1,156,500

* These processes are directly part of the incineration/steam generation process are therefore are considered a system operating cost. No cost credit to the incineration/heat recovery system can be claimed for these uses.

** These steam uses are external to the incineration/steam generation system, therefore a cost credit can be taken for these uses.

*** The dollar value of this steam is based on the cost to generate steam using the auxiliary boilers. The auxiliary boilers generate steam at a fuel cost of $2.98/1000 lb. steam.

3. System Energy Credit

A. BTU Credit

Process	Annual Steam Use (lb/year)	Electrical Savings* (kw-hr/year)	Total Energy Credit** (BTU/year)
Chlorination System	319,420	—	4.73 * 10^8
HVAC System	205,952,700	—	3.05 * 10^11
Misc. Turbines	—	2,205,400	2.20 * 10^10
Total	206,272,120	2,205,400	3.27 * 10^11

* Based on $.037/kw-hr
** Based on the following conversion factors

Steam	1481 Btu/#steam
Electricity	10,000 Btu/kw-hr

B. Cost Credit

Process	Cost Credit
Chlorination System	$ 1,000
HVAC System	$ 613,700
Misc. Turbines	$ 81,600
Total Credit	$ 696,300

XII. AIR EMISSIONS CONTROL

1. GENERAL INFORMATION

Technology:

Venturi wet scrubber (30 inches pressure drop) and packed tower (6 foot deep; 2 to 3 inches pressure drop) arranged in series. Each furnace has a top hearth (zero hearth) afterburner which is currently not used. Flue gases sequentially pass through a waste heat boiler, an economizer section, a precooler, a venturi scrubber, a subcooler, a mist eliminator, and an I.D. fan.

Precoolers:

Normal Pressure Drop	0.5" w.c.
Outlet Temperature	180 F
Water Flow Rate	250 gpm

Venturi Scrubbers:

Operating Pressure	
maximum	33" w.c.
minimum	20" w.c.
Water Flow Rate (maximum)	
venturi nozzle	250 gpm
venturi weir	250 gpm
Liquid To Gas Ratio	10 gal/1000 ACFM

Gas Temperature:

Inlet	180 F
Outlet	130 to 150 F

Subcooler:

Pressure Drop	2.0" w.c.
Inlet Temperature	130 - 150 F
Outlet Temperature	60 - 80 F
Water Flow Rate (maximum)	2000 gpm
Liquid To Gas Ratio	33 gal/1000 ACFM
Diameter	10 feet
Mist Eliminator	polyprolyene mesh packed tower - 3 trays

Emissions Standards:

opacity	20 units for any 6 minute average
particulates	1.3 #/dry ton feed
odor	150 odor units/#

Results of Last Emissions Test:

Parameter	Stack No. 8 June 7, 1988 *	Stack No. 10 June 28, 1988 *
Copper	175	330
Nickle	31	27
Lead	325	551
Zinc	2484	4306
Cadium	469	611
Chromium	53	40
Arsenic	25	31
Selenium	15	24
Particle Mass Emission (lbs/dry ton)	0.786	1.290

* All units are micrograms/ cubic meter unless otherwise noted. Complete test results are appended to this report.

Opacity is monitored continuously and recorded on a strip chart. Violations are noted automatically on the chart. During 1986, flue gases were in compliance with opacity emissions standards 99.93% of the time.

Stack height: Original 80 foot

Have added silencers which have increased the stack height by 10 feet. These silencers reduce noise emissions from the ID fans.

Building Height: about 65 feet

Stack Diameter: foot

Scrubber Water Treatment: Returned to primary treatment.

Scrubber Water Characteristics: 7,060 gpm (includes all coolers and scrubbers)
10 mg/l TSS
10 mg/l BOD

XIII. ASH DISPOSAL

1. GENERAL INFORMATION

Technology:

Ash has been disposed at on-site ash ponds since incineration began in 1938. Four ponds with a total volume of 250,000 cubic yards are available on-site. Wet ash is stored in these ponds and the supernatant from the ponds is pumped back to the aeration tanks.

For a period of time, a contractor was removing ash from the pit and transporting the ash by railroad to South Dakota to be processed for the recovery of precious metals. This company removed about 2/3 of the ash that had been accumulating in the pit since 1938. The removal of this ash has created a great deal of on-site ash disposal capacity. The contract for ash removal was canceled this year.

Location of Ash Landfill (on-site/off-site): On-site

Total Annual Volume of Ash Generated (cy/year): 42,600 cy/year
(33 #/cf and 52 tpd)

2. COST INFORMATION

A. Capital

Cost of Truck(s): $70,0000

Tipping Fee at Landfill (if commercially operated): N/A

B. O&M

O&M costs for the ash removal system are included in the incineration O&M costs (Section XI).

XIV. BIOLOGICAL SIDESTREAM (RECYCLE) TREATMENT

1. GENERAL INFORMATION

Technology:	Rotating Biological Contactors (RBC)
Date Installed:	1979-1980
Manufacturer:	Autotrol
No. Units:	50

2. DESIGN INFORMATION

RBC Units

No. Units	50
Diameter	12 feet
Length	23 feet
Unit Surface Area	90,000 square feet
Total Surface Area	4,500,000 cubic feet]

Final Settling Tanks

No. Units	2
Width	37 feet
Length	91 feet
Depth	12.5 feet
Overflow Rate	200 gpd/square foot

3. Operating Information

Source of Flow:

Overflow from thermal conditioning (Zimpro) decanting tanks. Overflow from the DAF thickeners used to dilute the Zimpro stream.

Flow Treated (gpd): 1.38 mgd

	INFLUENT	EFFLUENT
Soluble BOD (mg/l):	2056 *	699
TSS (mg/l):	1135	792

* Note that influent BOD and TSS values are low because the influent waste stream is diluted to reduce the water temperature from about 100 F to about 85 F. Decant overflow averages about 8,400 mg/l BOD and 18,900 mg/l COD.

Sludge Disposal:

Waste sludge from the RBC system (about 9 tpd) is incorporated into the DAF influent for treatment and disposal.

4. COST INFORMATION

A. Capital

Facilities Plan Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders):

Facilities were constructed from 1978 to 1982 at a cost of $14,079,900 (Project No. 400). Costs updated to a September 1988 ENR of 4535 are as follows:

equipment	$ 4,150,500
structural	$ 15,828,400
Total	$ 19,978,900

These facilities include the rotating biological treatment system (50 RBC units), two settling tanks for the RBC system, and two physical-chemical treatment systems (see Section XV).

These facilities were modified in 1983 - 1984 at a cost of $1,706,300 (Project No. 400A). These modifications included the acid proof lining of concrete surfaces, installation of additioal piping and pumps, and repairs to fiberglass dome covers. Project costs updated to a September 1988 ENR of 4535 are as follows:

equipment	$ 331,000
structural	$ 1,551,700
Total	$ 1,882,700

For additional project description, reference the appended advertisement for bids for Project No. 400 and Project No. 400A.

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	11 hr/day	$ 73,900
Maintenance Labor	25 hr/day	$ 200,750
Chemicals		$ 69,000
Electricity	2,740,000 kw-hr/year *	$ 80,900
Materials & Supplies		
- operations		$ 35,600
- maintenance		$ 52,500
Contracted Services (maintenance)		$ 11,800
Total		$ 524,450

* Based on 1987 Region II Utility Summary Sheets

5. ENERGY CONSUMPTION

Equipment	HP	NO. UNITS	HRS/DAY	KW-HR/DAY
RBC Shaft Drives	7.5	50 total 28.4 operating on average	24	3810

Annual Electrical Requirements (kw-hr/year): 2,740,000 (metered)

XV. PHYSICAL-CHEMICAL SIDESTREAM (RECYCLE) TREATMENT

1. GENERAL INFORMATION

Technology: Flocculation/Sedimentation with Lime, Ferric, or Polymer

Date Installed: 1979 to 1980

Source of Flow: Overflow from gravity and DAF thickeners.
Sidestream from roll presses.

This system is no longer used, therefore no operating information, capital or O&M costs will be presented.

XVI. ODOR CONTROL SYSTEMS

The following odor control systems are used to treat odorous off-gases from solids handling processes:

Process Area	Odor Control System
DAF Thickener Area	2 stage, packed bed chemical scrubber (4 units)*
Sludge Storage Tanks	2 stage, packed bed chemical scrubber (1 unit)
Sludge Processing Building	Odorous gases to incineration (2 units)**
Decant Tanks	Odorous gases to incineration
Sludge Holding Tanks	Odorous gases to incineration
RBC Disk Area	See DAF Thickener area *
RBC Settling Tanks	2 stage, packed bed chemical scrubber (1 unit)

* The DAF thickener area and the RBC disk area share this odor control system, although the system is currently used primarily for the RBC system.

** This includes odorous gases from the dewatering area.

Odor control for each process area will be detailed below. Although odorous gases from many process areas are used as combustion air in the incineration system, not all odorous gas streams can be treated in this manner because of the limited air requirements of the incineration system. Therefore, some wet scrubbing systems are necessary.

A. Sludge Storage Tanks

1. GENERAL INFORMATION

Technology: Two stage, packed bed, countercurrent flow, chemical scrubber

Date Installed: 1979

No. Systems: 2

2. Operating Information

Source of Gas Flow: Sludge storage tanks

Average Gas Flow Treated (cfm): 22,000

Chemical Dosage:

Sodium Hydroxide/Potassium Hydroxide 50 gpd (50% solution)
Sodium Hypochlorite 50 gpd (15% solution)

3. COST INFORMATION

Capital and O&M costs for this system are included in the costs presented in Section VI of this report (Sludge Storage Section).

4. ENERGY CONSUMPTION

Equipment	HP	No. Units	Operation Hrs/Day	Kw-hr/Day
Chemical Feed Pumps	50	8 total 2 operating	24	1790
ID Fans	100	4 total 1 operating	24	1790
Other	2	2	20	60
Total				3640

Annual Electrical Requirements (kw-hr/year): 1,328,600 (based on connected horsepower)

B. RBC Disk Area

1. GENERAL INFORMATION

Technology: Two stage, packed bed, countercurrent flow, chemical scrubber

Date Installed: 1978

No. Units: 4

2. Design Information

System Capacity: 3 units at 18,000 acfm
1 unit at 25,000 acfm

Static Pressure: 3 units at 14 inches w.c.
1 unit at 15 inches w.c.

3. Operating Information

Source of Gas Flow: RBC disk area
Note that this system can also treat off-gases from the DAF thickener building, although this capability is currently not used.

Average Gas Flow Treated (cfm): 25,000 cfm

Chemical Dosage:

Sodium Hydroxide/Potassium Hydroxide - about 600 gpd (50% solution)
Sodium Hypochlorite - 600 gpd (15% solution)

4. COST INFORMATION

Capital costs for this system are included under Section IV (Project No. 400). O&M costs are split between the DAF thickeners (Section IV) and the RBC sidestream treatment system (Section XIV).

5. ENERGY CONSUMPTION

EQUIPMENT	HP	NO. UNITS	HRS/DAY	KW-HR/DAY
Chemical Feed Pumps	50	8 total 2 operating	24	1790
ID Fans	100	4 total 1 operating	24	1790
Other	2	2	20	60
Total	152			3640

Annual Electrical Requirements (kw-hr/year): 1,328,600 kw-hr/year

C. RBC Settling Tanks

1. GENERAL INFORMATION

Technology: Two stage, packed bed, countercurrent flow, chemical scrubber

Date Installed: 1978

No. Systems: 1

2. Operating Information

Source of Gas Flow: RBC Settling Tank

Average Gas Flow Treated (cfm): 6000

Chemical Dosage:

Sodium Hydroxide/Potassium Hydroxide 100 gpd (50% solution)
Sodium Hypochlorite 100 gpd (15% solution)

3. COST INFORMATION

Capital and O&M costs for this system are included under Section XIV (RBC treatment systems) of this report.

4. ENERGY CONSUMPTION

Equipment	HP	No. Units	Operation Hrs/Day	Kw-hr/Day
Chemical Feed Pumps	20	4 total 2 operating	24	700
ID Fans	40	1	24	700
Other	5	1	20	75
Total				1475

Annual Electrical Requirements (kw-hr/year): 538,400 kw-hr/year (Based on connected horsepower)

XVII. COST SUMMARY TABLES

The following tables attempt to (1) estimate a reasonable construction cost for the existing Metropolitan WPCF solids handling facilities in 1988 dollars; (2) convert the construction cost to an annual cost; and (3) present a total annual cost (capital plus O&M) for each unit process. Capital costs have been estimated by updating the original construction costs to 1988 dollars using the Engineering News record (ENR) cost index. Operation and maintenance costs have been summarized based on the tables presented earlier in this report.

It should be emphasized that construction costs for such a facility are very difficult to estimate and, even if estimated accurately, are very difficult to use in comparison with other facilities. In reviewing these costs, the reader should consider the following comments:

- Building prices for two similiar facilities can be very different depending on such site-specific factors such as depth of ledge, local materials costs, site constraints, construction market conditions, or other construction considerations.

METRO WPCF
CONSTRUCTION COSTS

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4535)	AMORTIZED CAPITAL COST
W.A.S. Thickening		
-structures	$15,828,400	
-equipment	$4,150,500	
-total	$19,978,900	$1,750,000
Primary Sludge Thickening		
-structures	$5,400,000	
-equipment	$500,000	
-additional structure	$235,500	
-additional equipment	$21,800	
-total	$5,900,000	$526,000
Thermal Conditioning		
-structures	$26,400,000	
-equipment	$10,972,000	
-total	$37,372,000	$3,331,000
Sludge Dewatering *		
-structures	$778,400	
-equipment	$3,994,900	
-total	$4,773,300	$472,000
Sludge Incineration		
-structures	$92,759,900	
-equipment	$30,776,300	
-total	$123,536,200	$10,913,000
RBC Sidestream Treatment		
-structures	$17,380,100	
-equipment	$4,481,500	
-total	$21,861,600	$1,914,000

* Based on roll press dewatering capital costs.

METRO WPCF
ANNUAL COSTS FOR SOLIDS
HANDLING PROCESSES

PROCESS	CAPITAL	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS & SUPPLIES	CONTRACTED SERVICES	TOTAL ANNUAL COST	COST CREDIT	NET ANNUAL COST	% TOTAL NET COST	CAPITAL $/DRY TON (1)	O&M $/DRY TON (2)	TOTAL $/DRY TON
Sludge Pumping (3)	(4)	$0	$145,100	$0	$0	$0	$0	$145,100	$0	$145,100	0.42%	---	$2	$2
W.A.S. Thickening	$1,750,000	$683,100	$323,700	$0	$0	$240,400	$3,500	$3,000,700	$0	$3,000,700	8.72%	$20	$19	$39
Primary Sludge Thickening	$526,000	$419,400	$36,700	$0	$15,000	$45,300	$11,000	$1,053,400	$0	$1,053,400	3.06%	$6	$8	$14
Sludge Storage Tanks	(5)	$716,400	$110,200	$0	$28,500	$49,500	$700	$905,300	$0	$905,300	2.63%	---	$14	$14
Thermal Conditioning	$3,331,000	$1,550,300	$311,100	$0	$22,700	$239,300	$17,300	$5,471,700	$0	$5,471,700	15.90%	$38	$33	$71
Sludge Dewatering (6)	$472,000	$1,757,300	$169,200	$0	$780,600	$85,500	$4,800	$3,269,400	$0	$3,269,400	9.50%	$5	$43	$49
Sludge Incineration	$10,913,000	$4,299,300	$679,300	$129,900	$0	$558,000	$104,400	$16,683,900	$0	$16,683,900	48.48%	$125	$89	$214
Boiler System	(7)	$1,073,200	$223,700	$627,400	$55,500	$151,200	$9,600	$2,140,600	$696,300	$1,444,300	4.20%	---	$22	$22
EDC System	$1,914,000	$274,650	$80,900	$0	$69,000	$88,100	$11,000	$2,438,450	$0	$2,438,450	7.09%	$22	$8	$30
TOTAL	$18,906,000	$10,773,650	$2,079,900	$757,300	$971,300	$1,457,300	$163,160	$35,108,550	$696,300	$34,412,250	100.00%	$216	$239	$455

(1) Based on design capacity of 240 dry tons per day.
(2) Based on average day sludge production of 177.5 dry tons per day of dewatered cake.
(3) This line item includes pumping from the primary and secondary clarifiers to the sludge thickening process.
All subsequent sludge pumping is included in the appropriate unit process line item.
(4) Included in unit process capital costs
(5) Included in thermal conditioning capital costs
(6) Based on roll press dewatering costs
(7) Included in the incineration capital costs

Note: All costs are based on 1987 consumption records.
All capital costs based on September 1988 cost index.

- The amount of reserve capacity built into a facility can significantly affect construction costs. The amount of reserve capacity allowed for during design can depend on several factors such as site-specific constraints, plans for future expansion or growth, and the design consultant's philosophy concerning system redundancy.

In converting the estimated construction cost to an annual cost, it was assumed that all structures would have a useful life of 40 years and all equipment would have a useful life of 20 years. A discount rate of 8 percent was assumed to determine the capital recovery factor. Capital costs for the dewatering system reflected the costs for the roll press dewatering system only.

XVIII. SUMMARY OF ENERGY REQUIREMENTS

The following table summarizes energy consumption requirements for each unit process. To allow a true comparison of energy efficiency with other facilities, each form of energy consumption (electricity, fuel oil, natural gas, steam) has been converted to a common unit (BTUs). The energy consumption of each unit process has been determined based on tables presented earlier in this report. Energy credits have been accounted for where applicable. The net energy consumption for each unit process and for the system as a whole has been determined and expressed on a per ton basis. Factors used to convert each energy form to a BTU basis appear at the bottom of the table. These factors reflect the BTUs of energy required to produce a kw-hour of electricity and a pound of steam. These conversion factors account for inefficiencies in the production of electricity and steam.

XIX. LESSONS LEARNED

The operating experience at the Metro Facility provides some insights into fuel efficient incinerator operation.

Storage in the sludge handling train is essential. Storage helps the operator maintain a steady sludge feed to the incinerator in terms of quality and quantity and it allows the operator to completely shut down the system for short periods of time to perform regular maintenance tasks.

Communication between the operators of different processes, between the operators and maintenance crews, and between operators on different shifts developes consistency in the system's operation and creates an atmosphere of cooperation amoung the entire staff. This works to improve the consistency and the quality of the sludge feed to the incinerator. A daily newsletter is distributed to the staff to inform them of pertinent information such as operational problems that transpired the previous day, how these problems were resolved, and how these problems could be avoided in the future. The staff also forms committees comprised of engineers, operators, and maintenance personnel to discuss O&M problems. Each commitee addresses a particular problem. The commitee will evaluate a problem, brainstorm for solutions, and recommend process improvements and modifications to resolve the problem. The committee will then continue to

METRO WPCF
ENERGY REQUIREMENTS FOR SOLIDS
HANDLING PROCESSES

PROCESS	ENERGY CONSUMPTION ELECTRICITY (KW-HR/YEAR)	FUEL OIL (GAL/YEAR)	NATURAL GAS (CF/YEAR)	TOTAL BTUs CONSUMED	ENERGY CREDIT STEAM (#/YEAR)	ELECTRICITY (KW-HR/YEAR)	TOTAL BTU CREDIT	NET BTU CONSUMPTION	% TOTAL NET BTU CONSUMPTION	BTU/DRY TON *
Sludge Pumping	3,920,500	0	0	39,205,000,000	0	0	0	39,205,000,000	7.42%	605,132
W.A.S. Thickening	8,318,400	0	0	83,184,000,000	0	0	0	83,184,000,000	15.75%	1,283,951
Primary Sludge Thickening	857,600	0	0	8,576,000,000	0	0	0	8,576,000,000	1.62%	132,371
Sludge Storage	2,864,000	0	0	28,640,000,000	0	0	0	28,640,000,000	5.42%	442,061
Thermal Conditioning	7,645,000	0	0	76,450,000,000	0	0	0	76,450,000,000	14.47%	1,180,012
Sludge Dewatering	4,600,000	0	0	46,000,000,000	0	0	0	46,000,000,000	8.71%	710,014
Sludge Incineration	18,139,000	0	68,359,000	249,749,000,000	0	0	0	249,749,000,000	47.28%	3,854,895
Boiler System	6,046,300	0	236,064,500	296,527,500,000	206,272,100	2,205,400	327,542,980,100	(31,015,480,100)	-5.87%	(478,726)
RBC Treatment System	2,740,000	0	0	27,400,000,000	0	0	0	27,400,000,000	5.19%	422,921
TOTAL	55,130,800	0	304,423,500	855,731,500,000	206,272,100	2,205,400	327,542,980,100	528,188,519,900	100.00%	8,152,630

NOTE:		
	Electricity	10,000 BTU/kw-hr
	Steam	1481 BTU/#
	Digester Gas	600 BTU/cf
	Fuel Oil	138,000 BTU/gal
	Natural Gas	1000 BTU/cf

* Based on 1987 sludge production of 177.5 dry tpd of dewatered sludge cake.

monitor progress in resolving the problem and decide if further corrective actions are necessary. Copies of some of the staff memorandums that have been developed as a result these committee meetings are appended to this report.

Management has created a very positive atmosphere to work in at the Metro Facility. By encouraging employees to pursue technical advancement through advanced education and professional organizations and by providing the staff with a budget that allows for experimentation and process improvements, management has developed a very motivated staff that is always looking for new ways to improve the solids handling processes.

Metropolitan
Waste Control
Commission

Office Memorandum

TO: All Concerned

DATE: 9-14-88

FROM: Dave Quast

SUBJECT: Scum System Meeting, September 7, 1988

A Scum System meeting was held on Wednesday, September 7, 1988, from 1:15 P.M. to 2:15 P.M. in the Training Room. The following people were present:

OPERATIONS:	SHOP:
Beecher Vallencourt Sr.	Jim Driver
Dan Nalezny	Reed Santa
Gene Law	Denis Gorecki
Dave Quast	
Jack Klein	

The following items were discussed:

1. SCUM DECANT ROOM EQUIPMENT

   a. Regarding the suggestions made at the last meeting to prevent running the Moyno pumps dry and wearing out stators prematurely, it was decided that installing a recirculation line around the pump is the best place to start. A description of a Pump Failure Detector was distributed to the maintenance personnel for review. This device (similar to a pressure switch) may also be tried.

   b. Lab results are expected this week from Twin Cities Testing regarding viscosity data of heated scum for pump design data. In-house lab results are also expected in the near future for BTU, TVS and scum particle size information which may illuminate reasons for scum pipe plugging and grinder failure.

   c. The final steps for the 200 gpm scum decant return pump are taking place. It may be ready for trial this week.

   d. The blue line Fisher back pressure controller was installed this week. Now the pressure is controlled in both scum loops without the need for adjustment. The 408 Scum System Data Sheet will be slightly modified to record the actual back pressure rather than the controller settings. Squeeze valves were also replaced during the last week of August. These will be inspected every 6 weeks.

e. The hot water system for flushing the loop lines and hosing down the floor was checked thoroughly. The heater can only keep the water heated to above 150°F if the flow is less than 60 gpm. To assure that flow doesn't exceed this, an orifice flow controller will be installed in the effluent water line going to the Pick Heater.

f. In an attempt to determine the cause of periodic surges of problems with scum equipment and pipes, scum samples are being analyzed. Four samples were submitted to the laboratory (an East and West Primary sample from two different days) for Total Volatile Solids and BTU analysis. The lab is devising a test for grit content and size in the scum. West and East Primary scum is also being kept separated to try to pinpoint problems.

2. SCUM PIPE

a. The loop line temperature and pressure monitoring on the computer will continue to be used as a tool for determining causes of plugged pipes and/or pump failure.

b. There may be a segment of scum pipe in the loop that has poor contact with the heat tape. The 300 foot loop lines will be inspected for any "dead spots".

c. Recent plugging at the prep units has not been related to any foreign particles in the lines out of the ordinary. It may be related to the hot air blow back. Air flow and temperature meters will be installed on the purge lines. A minor modification may be made if more air preheating is necessary.

d. The work order for the trial modification on prep unit #7 (to extend the 2" loop line and pump to the main floor closer to the incinerator port) has been written. The pipe design is being worked on.

3. SAFETY

a. Confined space training will take place at 2:00 P.M. on Wednesday, September 14, 1988 for A and B shifts in the F&I #2 Control Room. This training will briefly cover safety aspects of skimming tank cleaning. Safety plans more general confined space training by the end of the year for all operators.

b. Scum air sample results will be released soon.

3. SAFETY (Cont'd)

c. Some general safety aspects related to the scum decant room involving fire hazards and emergency procedures were brought up. These will be discussed with Safety.

The next meeting will be during the week of September 19, 1988. The time and place will be announced later.

DQ:BJ

APPENDIX B
UPPER BLACKSTONE
WATER POLLUTION CONTROL FACILITY

I. GENERAL INFORMATION

ADDRESS:	UPPER BLACKSTONE WPCF Route 20 Millbury, MA. 01527
Phone Number:	(508) 755-1286
Contact:	Arthur Levesque Plant Manager
Year Began Operation:	1976
Design Engineer:	Fay, Spofford & Thorndike George Reece
Design Average Flow:	56 MGD
Design Peak Flow:	Max Day 83 MGD Max Hour 119 MGD

	FY 1987	FY 1988
Average Flow:	36 MGD	33 MGD
Max Day Flow:	60 MGD	—
Average Influent BOD:	109 mg/l	121 mg/l
Average Influent TSS:	122 mg/l	151 mg/l
Average Effluent BOD:	7 mg/l	8 mg/l
Average Effluent TSS:	11 mg/l	11 mg/l

Influent loads have increased over the past year due to an increase in sludge and septage accepted from outside sources. Septage is fed directly into the influent stream at the head of the plant. Thickened sludge (> 4% solids) accepted from outside sources is added to the TWAS storage tanks. About 40 truckloads of septage and thickened sludge are now accepted daily.

Permitted Effluent CBOD: winter 30 mg/l
summer 10 mg/l

Permitted Effluent TSS: winter 30 mg/l
summer 15 mg/l

Other Effluent Requirements: Ammonia nitrogen requirements

- monitor effluent ammonia nitrogen concentration in May
- from June 1 to June 15, average weekly ammonia concentration < 5 mg/l
- from June 15 to Oct. 31, average weekly and average monthly ammonia concentration < 2 mg/l and daily peak concentration < 2.5 mg/l

Plant Overview: The liquid treatment train includes aerated grit removal, primary settling, activated sludge treatment, and chlorination prior to discharge to the Blackstone River. Nitrification is practiced from late May until October 31. Solids handling processes include flotation thickening of waste activated sludge, separate storage of thickened waste activated sludge (TWAS) and unthickened primary sludge, blending of the TWAS and primary sludges, sludge dewatering using belt filter presses, sludge incineration, and ash disposal by landfilling on-site.

A schematic of the solids train showing FY 1988 average process loadings is attached.

II. UNIT COSTS

Unit costs are based on 1987-1988 records.

ITEM	UNIT COST
Labor ($/hour)	12.50 (includes fringe benefits)
Polymer ($/liquid #)	0.0845
City Water ($/100 gal)	0.114
Electricity ($/kw-hr)	0.047
No. 2 Fuel Oil ($/gal)	0.59
Natural Gas ($/100 cf)	0.3564
Chlorine ($/ton)	450.00

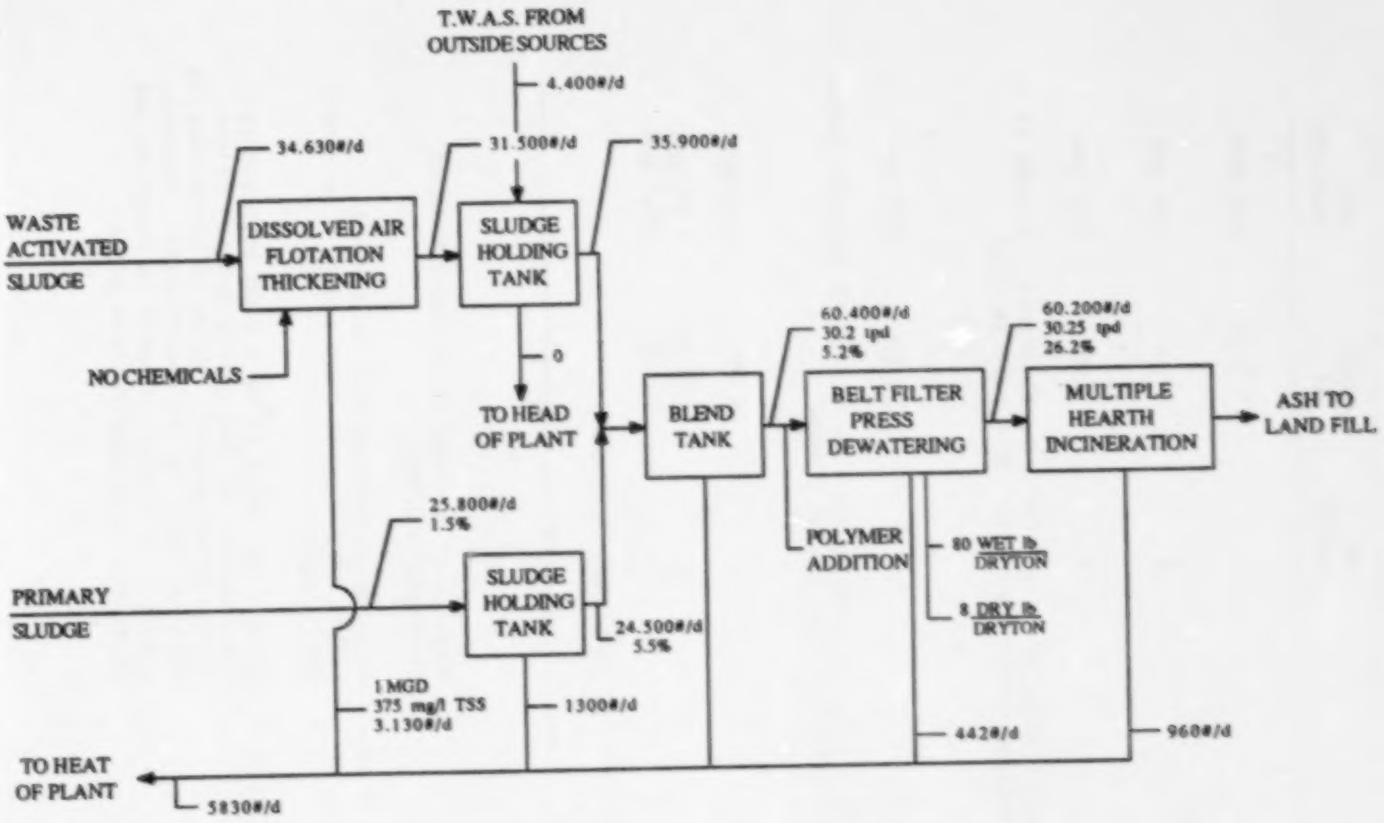
III. SLUDGE PUMPING

1. GENERAL

TRANSFER PUMP	NO. UNITS	UNIT HP	UNIT CAPACITY
Primary Sludge Pumps	6	7.5 HP	200 gpm
Waste Activated Sludge Pumps	3	5 HP	250 gpm
Thickened Waste Activated Sludge Pumps	4	5 HP	250 gpm
Note: 3 of the pumps are dedicated to the DAF top collectors. 1 pump is dedicated to the DAF bottom sludge draw off. This pump is used intermittently.			
Transfer from holding tanks (2) to blend tank	3	10 HP	230 gpm
Note: Usually, 2 of the 3 pumps are operated; 1 dedicated to primary sludge and 1 dedicated to thickened waste activated sludge			
Belt filter press feed pumps	4	5 HP	115 gpm
Plant water pumps	3	150 HP	2700 gpm
	2	50 HP	1000 gpm
Note: Usually 2 of the 2700 gpm pumps are operated.			

2. MAINTENANCE NOTES

Primary sludge pumps:	Require an average of 30 hours/week of maintenance time.
Waste activated sludge pumps:	Require an average of 4 hours/week of maintenance time to keep sludge flow meters calibrated.
Transfer pumps from storage tanks to blend tanks:	These pumps tend to be a high maintenance item because of the gritty quality of the sludge being pumped. About 16 hours/week is required for regular maintenance. Approximately $1,000/year is spent on supplies and materials to maintain these pumps.


T.W.A.S. FROM OUTSIDE SOURCES
4.400#/d
34.630#/d
31.500#/d
35.900#/d
WASTE ACTIVATED SLUDGE
DISSOLVED AIR FLOTATION THICKENING
SLUDGE HOLDING TANK
NO CHEMICALS
0
TO HEAD OF PLANT
60.400#/d
30.2 tpd
5.2%
60.200#/d
30.25 tpd
26.2%
BLEND TANK
BELT FILTER PRESS DEWATERING
MULTIPLE HEARTH INCINERATION
ASH TO LAND FILL
25.800#/d
1.5%
POLYMER ADDITION
80 WET lb / DRY TON
8 DRY lb / DRY TON
PRIMARY SLUDGE
SLUDGE HOLDING TANK
24.500#/d
5.5%
1 MGD
375 mg/l TSS
3.130#/d
1300#/d
442#/d
960#/d
TO HEAT OF PLANT
5830#/d

Upper Blackstone WPCF Solids Handling Schmatic.

3. COSTS

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	0 hr/day	$0
Maintenance Labor	50 hr/week	$32,500
Electricity	18,000 kWH/year	$800
Chemicals	None	
Materials & Supplies		$1,000
TOTAL		$34,300

Note: Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon curves presented in the EPA publication entitled Energy Conseration in Municipal Wastewater Treatment.

IV. WASTE ACTIVATED SLUDGE THICKENING

1. GENERAL INFORMATION

Technology:	Dissolved Air Flotation Thickeners (DAF)
Date Installed:	1976
Manufacturer:	Envirex
No. of Units:	4
Thickening Area (sf/unit):	1136
Sludge Volume Index (SVI):	60 to 200 depending on time of year.

2. OPERATING PARAMETERS

WAS to Thickening (#/day):	range 18,000 to 36,000 FY 1988 average 34,600 #/day
Design Average Loading Rats (psf/day):	10 without polymer
Design Peak Loading Rate (psf/day):	36 with polymer

Actual Average Loading Rate (psf/day): 6 without polymer

Actual Peak Loading Rate (psf/day): 8 without polymer

Air Pressure (psig): 40

Effluent Recycle Ratio (% of influent flow): 0

Hydraulic Loading:
W.A.S. Feed 300 gpm
Plant Water 110 gpm/unit
440 gpm total

Air to Solids Ratio (# air/# solids): Not Available

Typical depth of Sludge Blanket: 12 to 18 inches

Unthickened Percent Solids: typical .7% to .8%

Thickened Percent Solids: typical 4% to 5%

Chemical Addition (type & amount): Have ability to add polymer, but are currently not adding any chemical.

Solids Capture: 90+ %

Sidestream Strength (Q, TSS & BOD):
1 MGD
375 mg/l TSS
250 mg/l BOD

3. COST INFORMATION

A. Capital

Facility Planning Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders): Cost indexed to October 1973 ENR = 1934

Structures	$739,700
Equipment	$290,000
Total	$1,029,700

Includes costs for DAF thickeners, ancillary equipment, and building space.

Cost of Modifications/Expansions (year): None

B. O&M

O&M costs are based on Fiscal Year 1988 consumption records.

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	3 hr/day	$13,700
Maintenance Labor	10 hr/month	$ 1,500
Electricity*		
- Equipment	378,900 kWH/year	$17,800
- Building	770,000 kWH/year	$36,200
Chemicals	None	
Replacement Materials		$ 3,300
TOTAL		$72,500

*Reference Section 4 for basis of electrical consumption estimates.

Maintenance Concerns:	In 8 years, have spent about $20,000 on new chains. Every 5 years, about $4,000 is spent on a new gear drive. Other maintenance supply costs have been minor.

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of 60 KWH per dry ton (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities) and a consumption of 40 KWH per square foot of building space for lighting, HVAC, and other general building needs.

Typical Hours of Operation (hr/day):	4 units operating 24 hour/day
Electrical Requirements as Projected in Facilities Planning (kw-hr/yr):	Not Available

Estimated Annual Electrical Requirements (kw-hr/day):

Equipment	378,900
Building	770,000
TOTAL	1,148,900

V. SLUDGE STORAGE TANKS

Two storage tanks, one dedicated to primary sludge and one dedicated to thickened waste activated sludge are used to equalize the flow prior to dewatering.

The primary sludge storage tank acts as a gravity thickener. An overflow line returns a constant flow of supernatant to the primary settling tanks by gravity.

The waste activated sludge tank accepts thickened sludge from outside sources. These outside sources contributed about 2.2 tons per day of T.W.A.S. in FY 87. No mixing is provided in the T.W.A.S. holding tank. No supernatant is withdrawn from this tank.

1. GENERAL

No. Tanks:	2
Tank Size:	450,000 gallon
Tank Diameter:	55 ft
Tank Depth:	26 ft SWD
Aeration:	None
Mixing:	In the primary sludge tank, some agitation is provided by a shallow mechanical mixer, but complete mixing is not achieved. The mixer is primarily used to break up a scum layer that forms on the top of the tank. No mixing is provided in the waste activated sludge tank.

2. OPERATING INFORMATION

A. PRIMARY STORAGE TANK

Percent Solids of Sludge Feed:	range 1% to 5% average 1.5%
Percent Solids of Product:	range 5% to 10% average 5.5%
Chemical Addition:	None

Average Loading Rate: FY 1987 18,400 #/day
FY 1988 25,800 #/day

Hydraulic Sludge Feed: 200,000 GPD

Detention Time: 2.25 days (avg)

B. WASTE ACTIVATED STORAGE TANK

Percent Solids of Sludge Feed: 4% to 5%

Percent Solids of Product: 4% to 5%

Chemical Addition: None

Average Loading Rate: FY 1987: Estimated 38,100 #/day (includes thickened sludge from outside sources)

FY 1988: Estimated 35,900 #/day (includes thickened sludge from outside sources)

Detention Time: 4.7 days (avg)

3. COST

A. Capital

Facility Planning Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders): Costs indexed to October 1973
ENR = 1934

Structures	$291,000
Equipment	$ 60,000
Total	$351,000

Includes costs for holding tanks, building space, and sludge transfer pumps.

Cost of Modifications: No major modifications have been made.

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Maintenance Labor	200 hr/year	$2,500
Chemical Addition	None	
Plant Water	None	
Electricity	1,200 kw-hr/year	$ 100
Replacement Materials		$ 0
TOTAL		$2,600

Maintenance Concerns: Once each year, the primary sludge storage tank is taken out of service for a period of 10 to 14 days to be cleaned. During this period, 1 primary clarifier is used as a sludge storage tank. Cleaning labor totals about 200 manhours.

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of .25 KWH per dry ton (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities).

Rated HP of Mixer (primary sludge tank):	20 HP
Typical Hours of Operation:	3 hr/day (not used every day)
Estimated Electrical Requirements (kw-hr/yr):	1,200

VI. SLUDGE BLENDING TANKS

1. GENERAL INFORMATION

No. of Tanks:	2 (usually only 1 tank in use)
Tank Size:	20,000 gal/tank
Mixer Manufacturer:	Philadelphia

2. OPERATING INFORMATION

TWAS/Primary Sludge Ratio: typical 1.7 to 1.5 : 1 by volume

Average Detention Time: 3 hour

Percent Solids of Blended Sludge: 5% to 6%

3. COST INFORMATION

A. Capital

Facility Planning Estimate of Capital: Not available

Actual Capital Cost (bid + change orders): Included in cost of sludge processing complex.

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	1.5 hr/day	$ 6,800
Maintenance Labor	4 hr/month	$ 600
Chemical Additions	None	
Electricity	10,000 kw-hr/year	$ 500
Replacement Materials		$ 0
TOTAL		$ 7,900

Maintenance Concerns: Once per shift, rags that accumulate at the bar rack are raked. Once each month, the tank is taken out of service for 1/2 day to clean rags from the mixers.

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon curves presented in the EPA publication entitled Estimating Sludge Management Costs.

Rated HP of Mixers: 20

No. of Mixers: 1/tank

Typical Hours of Operation: 24 hrs/day (1 tank)

Estimated Electrical Requirements (kw-hr/yr): 10,000

VII. SLUDGE DEWATERING

The original plant design included 4 vacuum filters for sludge dewatering. Two of the original four vacuum filters have been replaced by plant staff with two belt filter press units. The two remaining vacuum filters are no longer used.

1. GENERAL INFORMATION

Technology: Belt Filter Press

No. of Units: 2

Unit Size: 2 meter belts

Date Installed: 1 in 1982
1 in 1985

Manufacturer: Komline-Sanderson

2. OPERATING PARAMETERS

Average feed to Dewatering (#/hour):

FY 1983	2725	FY 1986	2485
FY 1984	2500	FY 1987	2690
FY 1985	2525	FY 1988	2465

Average Hydraulic Loading:
sludge feed 100 gpm
polymer dosage 24 gpm
washwater 80 gpm

Parameter	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
Ton D.S. To BFP (tpd)	24.7	23.7	25.4	24.8	27.8	30.2
Avg % Volatiles	61.8	60.9	64.8	63.4	62.2	66.1
Avg Feed to Dewatering (#/hour)	2725	2500	2525	2485	2690	2465
Avg Loading Rates (#/m-hr)	1360	1250	1275	1240	1350	1230
BFP Cake (tpd)	84	73	96	92	100	115
Percent Solids of Feed	6.0	5.4	5.3	5.3	5.6	5.2
Percent Solids of Cake	28.1	26.0	26.5	27.0	27.6	26.2

Percent Solids of Cake:	Average 26% to 27% Range 22% to 36%
Belt Material:	Polypropylene
Polymer Type:	Liquid polymer Calgon WT2136
Polymer Dosage (#/ton dry solids):	80 to 100 wet pounds/dry ton solids
Frequency of Testing to Optimize Polymer Dosage:	No lab testing is performed. The operator adds just enough polymer to prevent sludge from squeezing out of the pressure zone of the BFP. Polymer was formerly prepared in a batch feed system. This resulted in significant waste. If the dewatering operation shut down unexpectedly during an operating period, the unused portion of the polymer batch would go bad during the down period and have to be discarded. The batch system also tended to produce an inconsistent polymer feed in terms of quality due to uneven mixing and varying polymer age. The batch system was replaced with a "Polyblend" system which produces the polymer mix on a continuous basis, thereby eliminating polymer waste and providing a consistent polymer blend. This system saved 15% in polymer costs in its first year of operation.
Other Chemicals:	Capability to apply lime and ferric chloride exists, but is not utilized.
Solids Capture:	95+ %
Sidestream Strength (Q, TSS & BOD):	1000 mg/l BOD 600 mg/l TSS pH = 6

3. COST INFORMATION

A. Capital Costs

Facility Planning Estimate of Capital: Not available

Actual Capital Cost (bid + change orders):

The original bid cost for the dewatering area was for a vacuum filtration operation. The dewatering area was subsequently modified to accomodate belt filter press units. Original bid costs are indexed to October 1973 costs (ENR = 1934)

Structures	$1,047,800
Equipment	$ 700,000
Total	$1,747,800

Cost of Modifications:

Two of the original vacuum filters have been removed and replaced with two belt filter press units, one in 1982 and one in 1985.

1982 unit: This unit was installed by the plant staff. Total cost was $105,000 for machine and rigger to install machine. This figure does not include the cost for plant labor or for a polymer system. The existing polymer system was modified for use with the BFP.

1985 unit: Was also installed by plant staff. Total cost was less than the 1982 unit cost.

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor*	39 hr/day	$177,900
Maintenance Labor**	78 hr/week	$ 50,700
Polymer	86 #/dry ton	$ 79,800
Other Chemicals	None	
Electricity***		
- Equipment	164,300 KWH/year	$ 7,700
- Building	1,046,600 KWH/year	$ 48,100
Replacement Materials****		$ 26,000
TOTAL		$390,200

* 1 operator 24 hour/day
1 senior operator 6 hour/day
1 swingman 9 hour/day

** The maintenance department considers the dewatering and incineration building as one work area. No distinction is made between time spent in the dewatering area and the incineration area. Two maintenance workers are assigned full-time to the dewatering/incineration area. One electrician and one instrumentation technician spend about 20% of their time in the dewatering/incineration area. For the purposes of this evaluation, it is assumed that these workers split their time 50/50 on the incineration and dewatering unit processes. Labor for general housekeeping duties and for oversight by the maintenance chief is also included in the labor estimate. The estimated maintenance hours breakdown as follows:

full-time technician	40 hours/week
electrical technician	4 hours/week
instrumentation technician	4 hours/week
general housekeeping	20 hours/week
maintenance chief	10 hours/week
Total	78 hours/week

*** See Section 4 for the basis of the estimate of electrical consumption.

****Replacement Materials: The original belts used lasted only 1200 hours per belt. These belts have been replaced with a seamless polypropylene belt that has a life of 5000 to 8000 hours per belt. A set of new belts costs about $6,000 and takes 3 men about 4 hours to install. Belts are replaced when the edges fray. Belts removed from the BFP units are re-used in other less wear applications. Other materials costs associated with the BFP are as follows:

Rollers/Bearings	$5,000/yr/BFP
Motors/Pumps	$3,000/yr/BFP
Support Equipment (Polymer feed, etc.)	$5,000/yr

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of 15 KWH per dry ton and a consumption of 40 KWH per square foot of building space for lighting, HVAC, and other general building needs (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities).

Typical Hours of Operation
(no. units;hrs/day): 1 unit - 24 hr/day

Estimated Electrical Requirements (kw-hr/year):

Equipment	164,300
Building	1,046,600
TOTAL	1,210,900

VIII. VACUUM FILTRATION DEWATERING

The following information regarding the former method of sludge dewatering, vacuum filtration, is provided for comparison purposes.

1. GENERAL INFORMATION

Technology:	Vacuum Filtration
No. of Original Units:	4
No. of Existing Units:	2 (could not now be used because discharge conveyor has been rerouted for BFP)
Unit Size:	12 foot diameter; 14 feet long; 528 SF effective area
Date Installed:	1976
Date Removed:	1 in 1982 1 in 1985
Manufacturer:	Envirex

2. OPERATING PARAMETERS

Percent Solids of Feed:	6% to 7%
Percent Solids of Cake:	28% to 29%
Chemical Dosage:	15 % Lime 4 % Ferric Chloride
Solids Capture:	Not as good as BFP units

3. ENERGY CONSUMPTION

Rated HP of Unit:	90 HP/unit
Typical Hours of Operation (no. units;hrs/day):	2 units at 24 hrs/day

IX. GRIT, SCREENINGS, AND SCUM DISPOSAL

GRIT DISPOSAL:	Landfilled
SCREENINGS DISPOSAL:	Landfilled

SCUM AND GREASE DISPOSAL:

Mixed with sludge in sludge blending tanks, dewatered, and incinerated. Typically, about 450 gpd of scum is processed. The plant staff has found that up to 1000 gpd of grease and scum can be processed without interferring with the dewatering process. Feed rates greater than 1000 gpd can blind the BFP belt, reducing the percent solids of the product cake.

X. INCINERATION

1. GENERAL INFORMATION

Technology:	Multiple Hearth Incineration
Date Installed:	1976
Manufacturer:	Envirotech
No. of Units:	3
No. of Hearths Per Unit:	10
Diameter:	22′ - 3″

2. OPERATING PARAMETERS

Cake Feed System:

A serpentix endless conveyor system that originally serviced the vacuum filters has been shortened and rerouted to receive cake from the BFP units. There is no cake storage between the BFP units and the MHF units, so a steady feed to the dewatering process must be maintained to create a uniform feed to the furnaces.

Design Peak Loading Rate:

18000 wet pounds per hour (4.6 wet pounds/sf hearth area) of dewatered cake with 20% solids and 70% volatiles

Average Loading Rate:

2500 dry pounds per hour (2.5 wet pounds/sf hearth area) of dewatered cake with 26% solids and 66% volatiles (FY 1988)

No. Units typically in Operation:	1 unit in operation 1 unit in stand-by mode 1 unit in clean/maintenance mode
Rotational Speed of Rabble Arms:	60 to 70 seconds per revolution
Percent Oxygen in the Exhaust Gas:	typically 10% to 11%

Average Volume of Shaft Cooling Air Returned As Combustion Air:

0 to 20% depending on the operator. Shaft air going up the stack rather than being recycled tends to act as a plume suppresant, especially in the winter.

Sludge Characteristics:

Last sludge analysis was performed in 1979 when lime and ferric were still being used for chemical conditioning prior to dewatering with vacuum filters. The results were as follows:

4380 Btu/# solids
10,000 Btu/# volatiles
41.7% volatiles

Temperature Profile of Incinerator (degrees F):

	1979	1988		1979	1988
Hearth 1	760	900	Hearth 6	480	400
Hearth 2	1025	1110-1570	Hearth 7	290	300
Hearth 3	1160	1190-1570	Hearth 8	190	200
Hearth 4	1460	760-1410	Hearth 9	145	150
Hearth 5	1380	590-1210	Hearth 10	130	100

In 1979, scum was injected directly into the furnace on hearth no. 5. This along with the changing characteristics of the sludge has altered the typical temperature profile (in 1979 were using vacuum filters with lime and ferric chloride sludge conditioning).

3. COST INFORMATION

A. Capital

Facilities Plan Estimate of Capital: Not available

Actual Capital Cost (bid + change orders):

Capital costs are indexed to October 1973 costs (ENR = 1934)

Structures	$1,543,000
Equipment	$3,083,900
Total	$4,626,900

Costs include the three incinerators, air pollution control equipment, ancilliary equipment, and structure.

Cost of Modifications: No major modifications have been performed.

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor*	42 hr/day	$ 191,700
Maintenance Labor**	84 hr/week	$ 54,600
Fuel Use		
- Natural Gas	6,789,000 cf/year	$ 24,200
- No. 2 Fuel Oil	31,848 gal/year	$ 18,800
Chemicals	None	
Electricity***		
Equipment	1,800,000 KWH/year	$ 82,800
Building	1,542,200 KWH/year	$ 70,900
Replacement Materials****		$ 53,300
TOTAL		$ 496,300

*		
	1 operator	24 hour/day
	1 senior operator	6 hour/day
	1 swingman	12 hour/day

** The maintenance department considers the dewatering and incineration building as one work area. No distinction is made between time spent in the dewatering area and the incineration area. Two maintenance workers are assigned full-time to the dewatering/incineration area. One electrician and one instrumentation technician spend about 20% of their time in the dewatering/incineration area. For the purposes of this evaluation, it is assumed that these workers split their time 50/50 on the incineration and dewatering unit processes. A third maintenance technician is assigned to the incineration area when an incinerator first comes off-line to begin the routine maintenance program. Labor for general housekeeping and for oversight by the maintenance chief has been included in the labor estimate. The breakdown for maintenance labor is as follows:

full-time maintenance technician	40 hours/week
electrical technician	4 hours/week
instrumentation technician	4 hours/week
general housekeeping	20 hours/week
maintenance chief	10 hours/week
swingman (2 months/year during incin. rotation)	6 hours/week
Total	84 hours/week

*** Reference Section 4 for the basis of the electrical consumption estimates.

****Instrumentation equipment costs about $30,000/year. Of this $30,000, about $20,000 is spent to buy new equipment to replace outdated technology and about $10,000 is spent on spare parts to keep the existing equipment operable. Installation of new, up-dated equipment often results in significant O&M cost savings. For instance, a recently installed oxygen analyzer has 1/2 the power draw of the former unit and has reduced the potable water use in the plant by 1/2.

Every 6 months, an incinerator is taken off-line for routine maintenance. This maintenance period begins by hiring an outside consultant to inspect the furnace for refractory damage. Because of the care shown by the operations staff in controlling temperature fluctuations during regular operation and during heat-up and cool-down periods, there has never been major refractory damage to any of the three incinerators. The plant staff follows up this inspection with an extensive maintenance program that is outlined in the following section. Typical materials costs for this maintenance program are as follows:

Refractory Inspection	$250/inspection $500/year
Rabble Tooth Replacement	$6,600/year
Refractory Repair	$3,800/year
Bearings	$1,700/year

These major cost items represent about 80% of the total maintenance cost for materials and supplies.

Maintenance Concerns:

The desired maintenance schedule is to rotate the three furnaces every 6 months between the operating, maintenance, and stand-by modes. Over the past few months, furnaces have been taken out of operation more frequently (every 2 to 3 months) due to the dropholes clogging more frequently. A significant increase in fuel use generally is a good indicator that some dropholes are clogged. The increase in drophole clogging is attributed to the changing characteristics of the sludge being processed (more thickened waste activated sludge and septage being accepted from outside sources).

It takes about 1 week for a furnace to cool from operating temperature to ambient temperature. It takes about 3 days and 1,000 gallons of fuel to heat the furnace from ambient temperature to operating temperature. In an emergency situation, a furnace could be taken out of service, have minor repair work completed, and returned to operation in a 2 week period.

During the 12 month shut-down period, the plant maintenance staff completes a 210 point checklist of items that must be inspected before the furnace is returned to duty. Each item is signed off both by the technician performing the inspection and a maintenance supervisor that reviews his work. Maintenance personnel consider the development of this checklist as a turning point in their operation. Prior to having the checklist, incinerators often had to be shutdown shortly after going on-line due to minor maintenance problems. During this period, the easy to check, high profile items were being addressed during the maintenance down periods, while less obvious, but equally important, maintenance items were being missed. These shut-downs were very costly in terms of fuel use and labor. Since the development of the checklist, incinerators have routinely completed the 6-month operation period with no need for maintenance shut-downs. Some of the major items that are checked are:

1. Clean all dropholes.
2. Clean any sludge build-up on the hearths.
3. Remove clinkers.
4. Remove build-up on burners.
5. Check cooling air fans, shaft air fans, and other equipment for signs of wear.
6. Rotate rabble teeth from hot hearths (hearth nos. 1 to 5) to cool hearths (hearths 6 to 10) to increase their useful life.

A complete copy of the checklist is appended to this report.

Operation Guidelines:

Operation of a MHF involves control of the following variables:

- rotational speed of the rabble arms
- excess air level
- auxiliary fuel use
- volume of shaft cooling air returned as combustion air
- volume of the sludge feed

There are no published rules that an operator must follow to insure that the furnace will perform properly. Operation of a MHF involves the manipulation of several variables which could be adjusted in different ways to achieve the same result. No two operators control the furnace in exactly the same way. However, operators at the Upper Blackstone facility are encouraged to achieve the following common goals:

- maintain a minimum combustion temperature of 1250 degrees F for air emissions control
- do not allow the combustion temperature to exceed 1500 to avoid clinkers
- burn as little auxiliary fuel as possible
- maintain a minimum excess oxygen level of 8 percent (dry basis) to insure complete combustion and avoid smoke in the stack exhaust
- maintain hearth no. 4 as the combustion hearth

The variables adjusted to achieve these goals are left to the operator's discretion, but minimization of fuel use is emphasized. The operators monitor the furnace by observing the stack exhaust, opening doors on the furnace to observe the fire itself, and observing the hearth temperature profile and the percent excess oxygen in the exhaust gas from the control panel. It is important that the operator directly observe the fire and the stack exhaust and not rely completely on temperature sensors because localized hot or cool spots may produce misleading readings.

As a result of maintaining a consistent temperature profile and maintaining controlled heat-up and cool-down periods, the 12 year old furnaces have never suffered any significant refractory damage. The operations staff has found that a 27% BFP cake (5.5% BFP feed) burns autogenously and is easy to control. At times the percent solids of the cake increases to 30-31%. At this percent solids, the incinerator is difficult to control because the sludge burns on the upper hearths, resulting in smoking problems.

Operator Training:

The Upper Blackstone facility has installed a job-rotation program in which operators are moved to a different area of the plant every two weeks. This job-rotation program has been a very effective management tool. It allows operators to understand and appreciate how the efficiency of a process is affected by the performace of the preceding unit and helps relieve the boredom and complacency that can result from operating the same piece of equipment each day. The job-rotation program encourages teamwork and focuses the operator's attention on the overall goal of saving fuel in the incineration system rather than on the operation of an individual process.

New emplyees assigned to the incineration area are teamed with a senior staff memeber who is very experienced in the operation of the incineration system. The senior staff member will provide hands-on operating training for the new employee. Generally, it takes about two months for a new operator to reach the point where he can monitor the furnace without direct supervision. At all times, a senior operator who is proficient in the operation of the furnace is on-duty within the plant. If conditions in the furnace begin to change, the junior operator can call on this senior operator for guidance. Although most operators are able to learn the basics of furnace operation in two months, there is no concrete schedule for operator training. Training time for each new operator must be determined on a case-by-case basis. Some operators become proficient in furnace operation very quickly while others take longer than two months to feel comfortable with the furnace.

Operation of an autogenous incineration facility requires knowledgeable, attentive, cooperative operators throughout the solids train. The implementation of the job-rotation program and the hands-on approach of management has helped develope such a staff at Upper Blackstone.

4. ENERGY CONSUMPTION

Equipment	Rated HP
Plant Water for Scrubber	150 (runs 120)
Induced Draft Fan	300 (runs 221)
Slurry Pump	75
Ash Vacuum Pump	40
Shaft Cooling Air Fan	20
Combustion Air Fan	40
Shaft Drive	15
Conveyors	5
Total	536

Records of actual metered electrical consumption are not available. Therefore, electrical consumption for equipment is estimated based upon Figure 3-113 of the EPA publication entitled Energy Consumption In Municipal Wastewater Treatment and electrical consumption for general building needs such as lighting and HVAC is estimated based upon a value of 40 KWH per square foot of building space.

Estimated Annual Electrical Requirements (kw-hr/year):

Equipment	1,800,000
Building	1,542,000
TOTAL	3,342,200

Annual Fuel Use:

Fiscal Year	BTU/Dry Ton	Gallons Fuel/Dry Ton
FY 83	556,500	4.0
FY 84	1,273,253	9.2
FY 85	577,265	4.2
FY 86	564,000	4.1
FY 87	977,416	7.1
FY 88	1,014,148	7.3

Includes start-up and cool-down fuel

Note: 1 therm natural gas = 100,000 Btu
1 gallon No.2 fuel oil = 138,000 Btu

Annual Fuel Use For Start-up and Cool-Down Periods (gal/year): about 2,000

XI. AIR EMISSIONS CONTROL

1. GENERAL INFORMATION

Technology:

Venturi wet scrubber and impingement tray scrubber arranged in series with a pressure drop of 20 inches w.c. No afterburner.

Date of Last Emissions Test:

All 3 furnaces were tested during start-up. In 1984, 1 furnace was tested. The results showed .69 # particulate per dry ton. No emissions testing has been performed since 1984.

Stack height: 75 foot

Stack Diameter: 4 foot

Exhaust Gas Flow: Typically about 21,000 cfm

Exhaust Temperature: Typically 100 F to 120 F

Scrubber Water Treatment: Returned to primary clarifiers

Scrubber Water Characteristics (Q,TSS,BOD): 1328 gpm (includes all coolers and scrubbers)
TSS 60 mg/l

XII. ASH DISPOSAL

1. GENERAL INFORMATION

Technology:

> Ash is removed from the lower hearth by a vacuum system and transferred to a storage silo. Three times each week, the silo is emptied and the ash is trucked to an on-site landfill.

Location of Landfill (on-site/off-site): on-site

Total Annual Volume of Ash Landfilled (cy/year): 4000 to 5000

2. COST INFORMATION

A. Capital

Cost of Truck(s): $43,000 (expected life 15 years)

Cost of Landfill (if owned by district): Not available

Tipping Fee at Landfill (if commercially operated): N/A

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST
Operations Labor	hr/day	$ 0
Landfill Maintenance*	36 hr/week	$ 23,400
Truck Mileage/Maintenance		$ 900
Materials/Supplies**		$ 5,000
TOTAL		$ 29,300

* 24 manhours/week for hauling
12 manhours/week for loading time at landfill

** Cover material is now applied at a 50/50 ash/cover ratio. Cover material is now obtained on-site. If State requirements for cover material change and cover material must be hauled to the landfill from an off-site location, cover material costs could increase to about $20,000/year.

XII. OPERATIONS MANPOWER ALLOCATION

The operations unit works 3 - 8 hour shifts per day. Each shift consists of 5 men allocated as follows:

1 senior plant operator
1 BFP operator
1 incinerator operator
1 operator dedicated to the liquid train
1 "inside man" who acts as a swing man for the solids handling processes. His responsibilities include checking the sludge blanket of the DAF units and adjusting the skimmer timer accordingly, emptying ash and clinkers from the incineration area, and general clean-up duties.

For the purposes of this evaluation, the hours for operators who split time between several processes have been further broken down as follows:

senior plant operator

incineration	6 hours/day
dewatering	6 hours/day
liquid end	12 hours/day

"inside man"

incineration	12 hours/day
dewatering	9 hours/day
thickening	3 hours/day

There are 20 people (4 crews) in the operations unit. Each day, 3 crews are on duty and one crew is off duty. On each crew, the operators are rotated every 2 weeks to a new position (BFP operator, incinerator operator, etc.) in an effort to develop a well-rounded staff that is knowledgeable of the entire system, rather than one unit process.

XIII. MAINTENANCE MANPOWER ALLOCATION

The maintenance unit works 1 - 8 hour shift, 5 days per week. The maintenance department consists of 16 people. Some maintenance workers are assigned full-time to a particular area of the plant while some workers move from area to area, depending on where the greatest need is. When an operations or maintenance staff member discover a maintenance problem, they fill out a work order and submit it to the maintenance department. Each morning, the maintenance chief reviews the work orders, consults with the senior plant operator if necessary, and prioritizes the work orders accordingly. An estimate was made of the breakdown of maintenance time dedicated to each unit process. The results are as follows.

1 maintenance chief
2 workers assigned full-time to the dewatering/incineration area
3 workers assigned full-time to plant housekeeping

3 workers assigned full-time to groundkeeping duties
1 worker assigned full-time to the machine shop
1 full-time clerk
1 worker assigned full-time to lubricating equipment as required
1 electrician who spends about 20% of his time in the dewatering/incineration area
1 instumentation technician who spends about 20% of his time in the dewatering/incineration area
2 workers assigned on an as-need basis

For the purposes of this evaluation, maintenance hours for people who split time between several processes were further broken down as follows:

maintenance chief

incineration	10 hours/week
dewatering	10 hours/week

Swingman assigned to incineration for 2 months/year during the period when incinerators are rotated.

housekeeping detail

incineration	20 hours/week
dewatering	20 hours/week

XIV. COST SUMMARY TABLES

The following tables attempt to (1) estimate a reasonable construction cost for the existing Upper Blackstone solids handling facilities in 1988 dollars; (2) convert the construction cost to an annual cost; and (3) present a total annual cost (capital plus O&M) for each unit process. Capital costs have been estimated by updating the original 1973 construction costs to 1988 dollars using the Engineering News Record (ENR) cost index. Operation and maintenance costs have been summarized based on the tables presented earlier in this report.

It should be emphasized that construction costs for such a facility are very difficult to estimate and, even if estimated accurately, are very difficult to use in comparison with other facilities. In reviewing these costs, the reader should consider the following comments:

- The original (1973) construction costs presented in this report are based on the project's Certificate of Completion. Many of the costs presented in this document are lump sum items that are included as a general construction cost. It is difficult to assign these costs to a particular unit process. We have, to the extent possible, attempted to apportion these construction costs to each unit process based on building areas, building volumes, or some other reasonable parameter. Still, it is difficult to accurately disaggregate many of the lump sum items into a cost for each unit process.

UPPER BLACKSTONE WPCF
CONSTRUCTION COSTS

PROCESS	ORIGINAL CONSTRUCTION COST (ENR = 1934)	UPDATED CONSTRUCTION COST (ENR = 4542)	ANNUAL CAPITAL COST
Waste activated sludge thickening			
-structures	$739,700	$1,737,200	$145,700
-equipment	$290,000	$681,100	$69,400
-total	$1,029,700	$2,418,300	$215,100
Sludge holding tanks			
-structures	$291,000	$683,400	$57,300
-equipment	$60,000	$140,900	$14,400
-total	$351,000	$824,300	$71,700
Sludge dewatering			
-structures	$1,047,800	$2,460,800	$206,400
-equipment	$700,000	$1,644,000	$167,400
-total	$1,747,800	$4,104,700	$373,800
Sludge incineration			
-structures	$1,543,000	$3,623,700	$303,900
-equipment	$3,083,900	$7,242,500	$737,600
-total	$4,626,900	$10,866,300	$1,041,500

UPPER BLACKSTONE WPCF
ANNUAL COSTS FOR SOLIDS
HANDLING PROCESSES

PROCESS	CAPITAL	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS	TOTAL ANNUAL COST	% TOTAL ANNUAL COST	CAPITAL COST $/DRY TON (1)	O&M COST $/DRY TON (2)	TOTAL COST $/DRY TON
Sludge Pumping	(3)	$32,500	$800	$0	$0	$1,000	$34,300	1.24%	$0.00	$3.12	$3.12
W.A.S. Thickening	$215,100	$15,200	$54,000	$0	$0	$3,300	$287,600	10.40%	$9.82	$6.60	$16.42
Holding/Blend Tanks	$71,700	$9,900	$600	$0	$0	$0	$82,200	2.97%	$3.27	$0.96	$4.23
Sludge Dewatering	$404,400	$228,600	$55,800	$0	$79,800	$26,000	$794,600	28.73%	$18.47	$35.52	$53.99
Sludge Incineration	$1,041,500	$246,300	$153,700	$43,000	$0	$53,300	$1,537,800	55.60%	$47.56	$45.17	$92.73
Ash Disposal	(4)	$23,400	$0	$900	$0	$5,000	$29,300	1.06%	$0.00	$2.67	$2.67
TOTAL	$1,732,700	$555,900	$264,900	$43,900	$79,800	$88,600	$2,765,800	100.00%	$79.12	$94.03	$173.15
With Afterburner										$129.03	$208.15

(1) Based on system design capacity of 60 dry tons per day.
(2) Based on FY88 average sludge production of 30.1 dry tons per day of dewatered cake.
(3) Included in unit process capital costs.
(4) Included in incineration capital costs.

NOTE: All costs based on FY 1988 consumption records.

- Building prices for two similiar facilities can be very different depending on such site-specific factors such as depth of ledge, local materials costs, site constraints, construction market conditions, or other construction considerations.

- The amount of reserve capacity built into a facility can significantly affect construction costs. The amount of reserve capacity allowed for during design can depend on several factors such as site-specific constraints, plans for future expansion or growth, and the design consultant's philosophy concerning system redundancy.

- The dewatering area at Upper Blackstone was originally designed for vacuum filters rather than belt filter press units. If the facility had originally been designed for belt filter press units, the dewatering area could have been much smaller, thereby significantly reducing construction costs.

- Based on recent manufacturer's quotes received for other projects, we believe that incineration equipment costs have increased at a greater rate than the ENR cost index. As a result, incineration equipment costs presented in this table may be low.

In converting the estimated construction cost to an annual cost, it was assumed that all structures would have a useful life of 40 years and all equipment would have a useful life of 20 years. A discount rate of 8 percent was assumed to determine an appropriate capital recovery factor.

XV. SUMMARY OF ENERGY REQUIREMENTS

The following table summarizes energy consumption requirements for each unit process. For the purposes of this table, the auxilliary fuel use for sludge incineration has been expressed in terms of gallons of No. 2 fuel oil, although in reality a combination of fuel oil and natural gas is used. The plant staff prefers to use natural gas as the auxilliary fuel source because it is more economical than fuel oil, but during winter months when the demand for natural gas is high, the District is forced to switch to fuel oil. Currently, the facility does not operate an afterburner as part of its emissions control system. The existing operation has been able to meet all current air emissions regulations without the use of an afterburner (reference air emissions section). It is difficult to predict future changes in air emissions standards and their subsequent affect on existing operations. However, if more stringent air emissions regulations are imposed in the future, the installation of an afterburner may be required at all sludge incineration facilities to control the possible products of incomplete combustion. Operation of an afterburner is very costly in terms of auxiliary fuel use. The lack of data regarding the composition of Upper Blacksone's sludge makes it difficult to project the exact amount of fuel that would be consumed by an external afterburner. However, based on experience at similiar facilities, it is estimated that operation of an external afterburner would increase auxiliary fuel use at the Upper Blackstone Facility from about 7 gallons of fuel per dry ton of sludge to about 67 gallons of fuel per dry ton. This would increase incineration costs by about $35 per dry ton of dewatered cake if fuel oil were used to fire the afterburner or about $29 per dry ton if natural gas were used. This potential increase in auxiliary fuel use is reflected in the attached table.

The Upper Blackstone incineration system does not utilize any heat recovery equipment. An Energy Audit Report prepared by CDM in 1982 investigated the cost effectiveness of installing a heat recovery system as a means of energy conservation. The system considered consisted of a series of heat exchangers which would recover heat from the flue gases to be used for heating water. The system would generate hot water at 140 F to be used mainly for heating the sludge management building and scum pipe cleaning. The system would be shutdown during the summer months when building heat is not required. It was determined that this system would result on approximately $13,100 in annual savings at a capital cost of $68,000 (1982 dollars), resulting in a payback period of 5.1 years. Several other energy conservation plans presented in the study had shorter payback periods. As a result, this heat recovery plan was never implemented. Because there is no obvious use for recovered heat at Upper Blackstone (such as year-round building heat or a sludge drying system), the implementation of a heat-recovery system has not been a priority item.

LESSONS LEARNED

Operating experience at the Upper Blackstone Facility provides some insights into fuel-efficient incinerator operation.

The use of storage and mixing tanks to maintain a consistent sludge feed to the dewatering and incineration processes is essential to avoid system upsets that would require the use of auxiliary fuel. A constant sludge feed is required to maintain optimum operating conditions.

The implementation of a job-rotation program has made the staff recognize that the success of the incineration process is dependent upon the performance of the preceeding solids handling processes. Operation throughout the solids train is focused on delivering a consistently dry feed to the incinerator. Operators at each step in the solids handling processes strive to remove as much water as possible from the sludge.

The development of an excellent maintenance program has increased the cost-effectiveness and fuel efficiency of the incineration process in several ways:

1. Reducing auxiliary fuel use by minimizing unscheduled maintenance shutdowns.
2. Minimizing costs for replacement materials by extending the useful life of furnace components such as the refractory brickwork and other ancilliary equipment.

UPPER BLACKSTONE WPCF
ENERGY REQUIREMENTS FOR SOLIDS
HANDLING PROCESSES

PROCESS	ELECTRICITY (KW-HR/YR) Building	Equip	Total	FUEL OIL (GAL/YEAR)	FUEL OIL (GAL/DRY	TOTAL BTU CONSUMPTION	BTU PER DRY TON
Sludge Pumping	--	18,000	18,000	0	0	0	0
W.A.S. Thickening	770,000	378,900	1,148,900	0	0	11,489,000,000	1,045,738
Holding/Blend Tanks	--	11,200	11,200	0	0	0	0
Sludge Dewatering	1,046,600	164,300	1,210,900	0	0	12,109,000,000	1,102,171
Sludge Incineration							
-without afterburner	1,800,000	1,542,200	3,342,200	80,200	7.3	44,489,600,000	4,049,479
-with afterburner	1,800,000	1,542,200	3,342,200	736,100	67	135,003,800,000	12,288,154

NOTE: Conversion factors used are as follows:
Electricity 10,000 BTU/KW-HR
Fuel Oil 138,000 BTU/gal

All figures are based on FY 1988 consumption records and
FY 1988 sludge production (30.1 tpd of dewatered cake)

3. Providing the operators the information necessary to operate the incinerator fuel-efficiently by keeping the instrumentation and monitoring equipment operable and up-to-date in terms current technology. For example, a key control parameter for the operator is the percent excess oxygen in the exhaust gas. However, an exhaust gas oxygen analyzer is a difficult piece of equipment to keep in operable condition because it is a fairly sensitive piece of equipment that must operate in a dirty, thermally stressful environment. At many facilities, the system's original oxygen analyzer is no longer functioning, but the plant staff has not bothered to replace the unit. As a result, the operators must, in effect, run the furnace blindly. At Upper Blackstone, equipment such as the exhaust gas oxygen analyzer is calibrated regularly and replaced if breakdowns make the equipment inoperable or if new, superior technology becomes available.

A major key to the success of this maintenance program has been the development of a 210 point checklist of items which must be addressed during a maintenance shutdown period. This insures that each incinerator is thoroughly examined before being returned to service, which in turn reduces repair costs and saves fuel by identifying minor problems before they become major problems and minimizing unexpected shutdowns during operation periods.

The sludge at Upper Blackstone dewaters exceptionally well. While this success can be partially attributed to operator attention, it is possible that an industrial influence in the influent wastewater stream has a positive affect on the dewatering characteristics of the sludge. The characteristics of each facility's sludge is influenced by the characteristics of that facility's influent stream. Some facilities may be fortunate enough to begin their solids handling process train with a sludge that by its nature dewaters better than sludge from similiar facilities.

INCINERATOR NO. ____ (PAGE 1 OF 6 PAGES)

OFF LINE _/_/_ EXPECTED ON LINE _/_/_

	DATE	INSP. BY	COMMENTS
FIRE BOX			
rabble down all ash			
clean drop holes			
inspect refactory & repair as necessary			
check burner cones - clean; look for "pot" holes - and fill w/ refractory castable			
inspect doors for cracks			
lubricate door pins			
rebrick doors			
clean and paint door as necessary			
RABBLE SYSTEM			
inspect all teeth			
swap upper teeth to lower hearth where possable			
replace burned & bent teeth			
inspect rabble arm & root for cracks			
check all lute caps			
CENTER SHAFT & DRIVE			
Drain & replace oil in step bearing			
clean & check bevel & pinion gear for wear and clearance			
regrease bevel & pinion gear			
grease upper bearing			
fill sand seals			
change oil in Falk reducer & drive			
check clutch for wear			
check clutch springs for proper tension			
check coupling & motor bearings			
check oil seals			
check Reeves drive-belts-sheave & bearings			
check mounting bolts			
clean & touch up paint			

(PAGE 2 OF 6 PAGES)

COOLING AIR SYSTEM	DATE	INSP. BY	COMMENTS
Check air intake raceway for water			
Check belts			
Lubricate motor & impeller bearings			
Repack incinerator shaft seal			
Clean impeller			
Check mercury switch			
Tighten hold down bolts			
Clean & touch up paint			
SLURRY PUMP			
Check belts			
Check seal & bearings			
Repack pump			
Lubricate & operate all valves			
Check check valve for wear			
Inspect hold down bolts			
Clean & touch up paint			
Lubricate motor & bearings-Check coupling			
ASH SYSTEM			
Clean lateral line			
Clean hopper			
Check bindicator probe			
Clean & lubricate air gate			
Clean & lubricate hopper door track & cable			
Tighten bolts			
Inspect & lubricate vacuum breaker			
Clean pit			

(PAGE 3 OF 6 PAGES)

	DATE	INSP. BY	COMMENTS
SCRUBBER SYSTEM			
Inspect & clean impingement plates			
Clean plant water flow meter			
Clean plant water strainer			
Check spray nozzles			
Inspect venturi & breaching for brick damage			
Operate venturi & check boot & pins			
Lubricate piston & guides			
Clean water seals			
Check plenum gaskets & tighten			
Lubricate & operate all valves			
BURNER SYSTEMS			
open burner fronts			
Inspect burner cone - look for deep cracks, crevasses, shifting, build ups, mis alignment.			
Clean nozzles & fins			
Clean scanner & pilot ports			
Set ignition points			
Inspect combustion air linkage			
Clean oil strainer			
Inspect & lubricate latch valve			
Inspect air, oil, and gas piping for leaks			
Check all gauges			
Operate & lubricate all valves			
Inspect high voltage wire (ignition)			
Inspect burner control box			

(PAGE 4 OF 6 PAGES)

	DATE	INSP. BY	COMMENTS
AIR SYSTEM			
Blow out all air lines			
Check drying system & strainer			
Check regulators			
Check all air gauges			
Fill all air lube jars			
Inspect piping for leaks			
OIL & GAS SYSTEM			
Rebuild Viking oil pumps			
Check all gauges			
Lubricate & operate all valves			
Inspect all piping for leaks			
Clean filters			
Operate Maxon valve			
Check oil tanks for water			
Inspect gas manafold & solenoids			
I.D. FAN			
REMOVE SHROUD			
Clean & balance impeller			
Inspect inlet & exhaust dampers			
Inspect & lubricate linkage			
Inspect air operators			
Clean brushes & commutator (motor)			
Inspect & lubricate coupling & motor			
Lubricate or repack bearings			
Inspect mount for cracks			
Check hold down bolts			
Inspect expansion boot			
SET VIBRATION METER [illegible]			
Clean & touch up paint SUPPORT			

	DATE	INSP. BY	COMMENTS
ORCED DRAFT FAN			
Check coupling			
Operate & lubricate damper valves			
Inspect air operator & speed control			
Inspected & lubricate bearing			
Tighten hold down bolts			
Clean & touch up paint			
COMBUSTION AIR FAN			
Clean immpeller & screen			
Inspect & lubricate coupling & bearings			
Tighten hold down bolts			
Clean & touch up paint			
CONVEYOR SYSTEM			
Clean belt & rollers			
Adjust belt for tracking			
Clean & lubricate scale linkage			
Clean & lubricate drop damper & chute			
Change scraper blade & adjust			
Calibrate scale			
Clean & touch up paint			
MISCELLANEOUS			
TORQUE STACK BOLTS			
Inspect & lubricate by pass damper			
Bolw scum lines			
Lift grates & clean incinerator top			
Touch up all paint			
Tighten all hangers & bolts			
INSPECT STACK FOR CORROSION			

ELECTRICAL	DATE	INSP. BY	COMMENTS
Air & vacuum clean all panels & controls			
Clean contacts on all starters & contactors			
Replace all light bulbs as necessary			
Inspect burner boxes & scanners			
Test anunciator system			
Operate all safety cutouts & interlocks			
Bump all motors			
Clean & touch up paint on panels			
Amp. + REG reading on all motors			
Clean REPLACE brushes on I.D. fan motor			
INSTRUMENTATION			
an all meters & recorders			
Calibrate all meters & recorders			
Replace all pads, ink & charts			
Inspect & calibrate o2 analyzer			
Replace damaged thermocouples			
Calibrate all thermocouples			
Test safety limits & trips			
Run 30 min. 66% test on scale			
Clean instrument air lines & filters			
Inspect terminal boards & strips			
Soap test instrument air lines			

APPENDIX C
DUFFIN CREEK
WATER POLLUTION CONTROL FACILITY

I. GENERAL INFORMATION

Address:

Duffin Creek WPCF
901 McKay Road
Pickering, Ontario
Canada L1W3A3

Phone Number:

(416) 686-2003 (main plant)
(416) 686-2007 (incin area)

Contact:

R.J. (Bob) Barnaby
Supervisor of Dewatering and Incineration

Design Engineer:

Proctor & Redfern
Dave Filman
(416) 445-3600

The following Proctor & Redfern study was used as the primary reference for all of the capital costs and many of the operation costs presented in this case study report:

"Development Of A Methodology To Investigate The Cost-Effectiveness Of Various Sludge Management Systems"; The Proctor & Redfern Group, January 1988.

Year Began Operation: 1980

Design Average Flow: 40 MIGD (48 MGD)

Design Peak Flow: 100 MIGD (120 MGD)

Current Average Flow: 42 MIGD (50 MGD)

Current Peak Flow: 100+MIGD

Average Influent BOD: 134 mg/l

Average Influent TSS: 196 mg/l

Average Effluent BOD: 19 mg/l

Average Effluent TSS: 10 mg/l

Permitted Effluent BOD: 15 mg/l

Permitted Effluent TSS: 15 mg/l

Other Effluent Requirements: Phosphorus 1 mg/l

Plant Overview:

Treatment processes in the liquid train include screening, grit removal with detritors, primary settling, phosphorus reduction with the addition of ferrous sulfate,conventional activated sludge process, secondary settling, and chlorination prior to discharge to Lake Ontario. The solids handling train includes co-settling of the primary and secondary sludges, anaerobic digestion, sludge storage, sludge dewatering with membrane filter presses, and incineration with a fluid bed reactor.

A plant expansion is currently in the design/bid phase. The expansion will increase plant capacity to 80 migd (96 mgd). The new liquid treatment facilities will mirror the existing facility. Improvements to the solids train will be performed in two phases. Additional digesters and membrane filter presses will be installed as part of the first construction phase. A third fluid bed incinerator will not be required until flows reach the 55 to 60 migd range (current flow is 42 migd), so installation of a third furnace will be delayed to the second construction phase. Additional details of the plant expansion will be provided in subsequent sections.

A schematic of the solids train showing 1987 average condition process loadings is attached.

II. UNIT COSTS

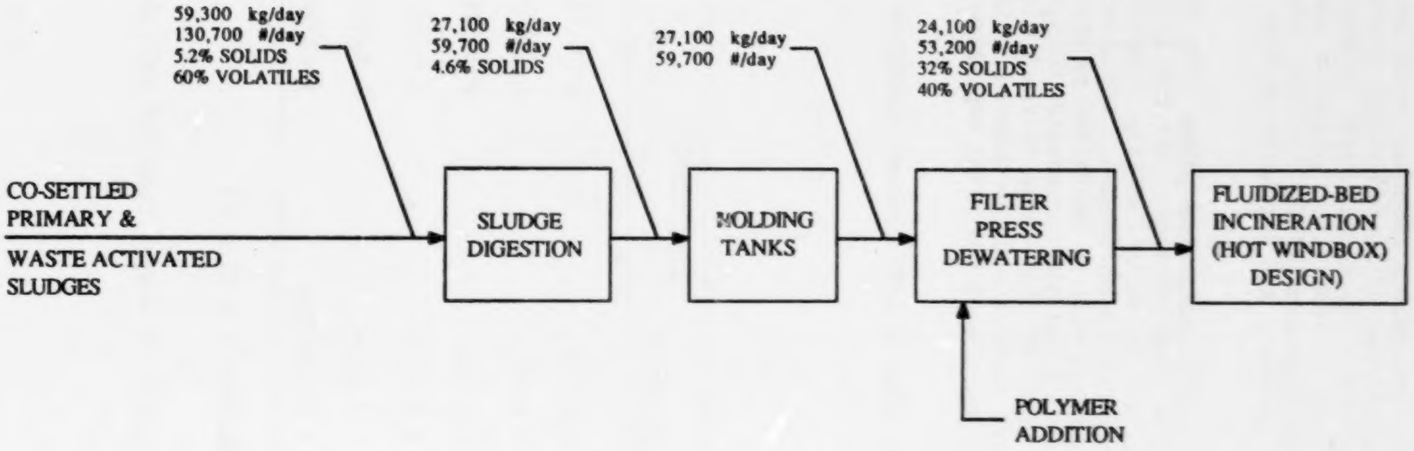
Base unit costs on 1987 records.

ITEM	UNIT COSTS* CANADIAN	UNIT COSTS* U.S.
Labor ($/hour)**	$ 17.94	$ 14.71
Polymer ($/kg,#)	$ 5.15/kg	$ 1.92/#
Electricity ($/kw-hr)	$ 0.045	$ 0.037
No. 2 Fuel Oil ($/liter,gal)	$ 0.237/l	$ 0.74/gal
Natural Gas ($/cubic meter, cubic foot)	$ 0.15/m	$ 0.35/100 cf
Steam***	$ 51/1000kg	$ 19/1000#

*Based on exchange rate of $1 Canadian = $.82 U.S.

**Includes employee benefits

***Unit price used in recording "sales" of energy from one unit process to another unit process.


59,300 kg/day
130,700 #/day
5.2% SOLIDS
60% VOLATILES
27,100 kg/day
59,700 #/day
4.6% SOLIDS
27,100 kg/day
59,700 #/day
24,100 kg/day
53,200 #/day
32% SOLIDS
40% VOLATILES
CO-SETTLED PRIMARY &
WASTE ACTIVATED SLUDGES
SLUDGE DIGESTION
HOLDING TANKS
FILTER PRESS DEWATERING
FLUIDIZED-BED INCINERATION (HOT WINDBOX) DESIGN)
POLYMER ADDITION

Duffin Creek WPCF Solids Handling Schematic

III. SLUDGE TRANSFER PUMPING

Records of actual metered electrical consumption are not available. Therefore, electrical consumption will be based upon curves presented in the EPA publication entitled Energy Conservation in Municipal Wastewater Treatment.

Transfer Pump	No. Units	HP	Kw-hr/ year	Annual Electrical Cost Canadian	U.S.
Raw Sludge Pumps	4	15	8,500	$400	$300
Digested Sludge Pumps	1	15	6,800	$300	$300
Filter Press Feed Pumps	4	30	1,500	$100	$100
Dewatered Cake Pumps*	1	75	1,000	$100	$100
TOTAL				$900	$800

*For further description of the incineration feed system, see Section IX.

IV. SLUDGE DIGESTION

1. GENERAL INFORMATION

Technology:	Anaerobic Sludge Digestion Two-stage digestion system
Date Installed:	1980
No. of Units:	4 (2 primary digesters and 2 secondary digesters)
Tank Height:	9.1 meters (30 feet)
Tank Diameter:	33.5 meters (110 feet)
Tank Volume:	8074 cubic meters/unit (285,000 cf/unit)
Type of Cover (fixed or floating):	Floating

External Heat Source (heat exchanger):

2 Leitch concentric tube heat exchangers per unit

2 Dorr-Oliver spiral heat exchangers per unit

The Leitch heat exchangers are the primary means of providing heat to the digesters. They serve to transfer heat from the plant hot water loop (75 C/167 F) to the primary digesters. The spiral heat exchangers were added in an attempt to utilize available heat from the flue gas scrubber water. The intent was to transfer heat from the scrubber water (90 F) to the digester sludge feed. This system has never operated for an extended period because of plugging problems on the sludge side of the exchanger. The plant staff is considering two solutions to this problem: (1) the installation of more narrow bar racks at the influent channel to reduce the size of particles in the sludge; and (2) using the spiral exchangers for heating plant water rather than heating sludge.

Operating History:

The digesters were originally installed as an interim sludge stabilization process. The liquid train of the original treatment facility was completed about one year before the solids train was scheduled for completion. Sludge was to be stabilized and landfilled until the incineration system was ready for operation. Digestion was to be used as the temporary stabilization process. When the incineration system was complete, the digesters were mothballed and the raw sludge was dewatered and incinerated. This operation resulted in a major odor problem. The staff concluded that raw sludge could not be processed without some odor control system for the dewatering and incineration areas. It was decided that the cheapest, easiest way to remedy the odor problem was to put the digesters back on-line. Operation of the digesters solved the odor problem. The solids handling processes are currently operating with virtually no noticeable odor. The only odor control technology used in the solids train is a chemical masking agent for the dewatering area. The use of digesters in the solids train has eliminated what was a serious odor problem. The destruction of volatiles in the digestion process would normally make digestion incompatible with an incineration process. This is not the case at Duffin Creek because the digester product gas is used to fire the hot wind box of the furnace. The loss of volatiles resulting from the digestion process is compensated for by the utilization of digester gas as a fuel source.

Future Operation:

Four new digesters (2 primary and 2 secondary) will be installed as part of the plant expansion.

2. OPERATING PARAMETERS

Type of Sludge Feed:	Co-settled primary and waste activated sludges
Solids Feed (kg/day):	59,300 kg/day (130,700 #/day)
% Volatiles of Feed:	60%(volatiles are low because of addition of ferrous sulfate for phosphorus removal)
Digested Solids (kg/day):	27,100 kg/day (59,700 #/day)
% Volatiles of Digested Solids:	40%
Degree of Stabilization (% reduction in volatile solids):	34%
Loading Rates:	2.4 kg volatile solids per cubic meter per day of digester capacity (.15 # volatile solids/cubic foot/day)
% Solids Feed:	5.2%
% Solids of Digested Solids:	4.6%
Continuous or Intermittent Feed:	Intermittent
Design Mean Cell Residence Time:	20 days
Actual Mean Cell Residence Time:	12.8 days
Operating Temperature:	primary units 37 C 99 F
Operating pH:	primary units 7.4 avg
Method of Mixing in Primary Tanks:	Gas recirculation with 6 Aero Hydraulic units per tank. The plant staff reported that mixing with these units is very poor. As part of the plant expansion, an external mixing system will be included in the new digesters and retrofitted in the existing digesters.
Supernatant Treatment	Returned to head of plant

Supernatant
Characteristics: Avg Q = 1364 cubic meter/day
TS = 2.3%

3. COST INFORMATION

A. Capital

Facilities Planning Estimate of Capital: Not Available

> A facilities planning level report was prepared in the early 1970s, but changes in the recommended plan that were made between the report and design stages were so substantial that the costs presented in the report would not be useful. The recommended plan presented in the report included thermal conditioning and did not include digestion or filter press dewatering. Also, the original plan was based on a 30 migd design flow rather than the final 40 migd design flow. For these reasons, costs presented in the facilities planning level reports were not considered relevent.

Actual Capital Cost (bid + change orders): See attached table.

Cost of Modifications/Expansions (year): None

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST CANADIAN	U.S.
Operations Labor	8 hr/day	$ 37,300	$ 30,600
Maintenance Labor	1 hr/day + 2 months/yr	$ 12,300	$ 10,100
Electricity	1,456,200 kw-hr/year	$ 65,500	$ 53,900
Chemicals	None		
Materials/Supplies		$ 9,000	$ 7,400
Other Purchased Services		$ 18,000	$ 14,800
Total		$142,100	$116,800

Note: The digestion and incineration processes are considered to be connected processes; therefore the digestion process does not take a credit for the digester gas used in the furnace hot wind box and the incineration process does not take a credit for heat provided to the digester building.

CAPITAL COSTS - SLUDGE DIGESTION

Contract No.	Major Cost Item	Construction/ Purchase Date	Construction ENR	Original Construction Cost (Canadian $1,000)	Updated Construction Cost * (Canadian $1,000)	Updated Construction Cost * (U.S. $1,000)
7	Gen. Construction	June 1977	2541	$2,894	$5,165	$4,235
	Purchased Equipment:					
7	Primary Covers	Feb 1977	2505	$423	$766	$628
7	Mixing Mechanism	Nov 1976	2486	$138	$252	$206
7	Secondary Covers	April 1976	2327	$712	$1,388	$1,138
7	Heat Exchangers	March 1976	2317	$79	$155	$127
7	Supernatant Selector	May 1976	2357	$54	$104	$85
7	Sludge Pumps	July 1976	2414	$36	$68	$55
19/20	Plant Changes	Sept 1982	3878	$56	$65	$54
19/20	Plant Changes	Nov 1982	3918	$49	$57	$47
	Total			$4,441	$8,018	$6,575

* Updated to September 1988 ENR = 4535

Source: This table is based on information presented in the Proctor & Redfern study entitled:

Development Of A Methodology To Investigate The
Cost Effectiveness Of Various Sludge Management Systems
January 1988

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of 60 KWH per dry ton (reference WPCF Manual of Practice No. FD-2 *Energy Conservation in the Design of Wastewater Treatment Facilities*) and a consumption of 40 KWH per square foot of building space for lighting, HVAC, and other general building needs.

Rated HP of Unit Mixers:	4 units at 15 HP/unit	
Electrical Requirements as Projected in Facilities Planning (kw-hr/yr):	Not Available	
Estimated Annual Electrical Requirements (KWH/yr):	Equipment	1,431,200
	Building	25,000
	TOTAL	1,456,200
Other Energy Consumptions:	None	
Volume of Gas Produced:	11,700 cubic meters/day	(413,200 cf/day)
Volume of Gas Used at Site:	8892 cubic meters/day	(314,000 cf/day)
Volume of Gas Flared:	2808 cubic meters/day	(99,200 cf/day)
Percent Methane in Product Gas:	Not Available	

Product Gas Uses:

When the furnace is operating, digester gas is always provided to the furnace hot wind box (HWB). If the fuel demand at the HWB exceeds the digester gas supply, the difference is made up with natural gas. The HWB temperature should not exceed 900 C (1650 F). If the available supply of digester gas exceeds the amount required to maintain a 900 C HWB temperature, the extra digester gas can be used to fuel an auxiliary boiler if there is a need for additional steam.

Auxiliary boilers are required to start the incineration system because the fluidizing air blowers are driven by steam turbines. The auxiliary boilers are also used to make up the difference between the plant's heating requirements and the heat production of the waste heat boilers.

Approximately 4900 cubic meters/day (173,500 cf/day) of digester gas is utilized in the hot wind box of the FBF. The balance is consumed in the auxiliary boilers. The plant staff is working to increase utilization of the digester gas. In the past, only one of the two auxiliary boilers could be operated using digester gas. The gas pressure was too low to allow both auxiliary boilers to operate simultaneously using digester gas. Therefore, some natural gas always had to be supplied to the auxiliary boilers. The staff is now in the process of refurbishing the boiler system such that both auxiliary boilers will be able to operate using digester gas alone with no natural gas.

V. SLUDGE HOLDING TANKS

These tanks serve to provide equalization storage within the solids train and blend the sludge from the 2 digestion systems into one homogenous sludge.

1. GENERAL

No. Tanks:	4
Tank Size:	60,000 gallon
Aeration:	None
Mixing:	Mechanical
Mixer Manufacturer:	2 - Lightnin Mixers 2 - Flight Mixers Note - Plant staff report that mixing in these tanks is inadequate.

2. COST

A. Capital

Facility Planning Estimate of Capital:	Not Available
Actual Capital Cost (bid + change orders):	Included in the dewatering area capital costs.
Cost of Modifications:	None

B. O&M

O&M costs associated with the sludge holding tanks are very minor. These tanks are maintained by the dewatering staff; therefore the O&M costs for the tanks are included in the dewatering budget.

3. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon curves presented in the EPA publication entitled Estimating Sludge Management Costs.

Rated HP of Mixer: 4 at 7.5 HP; 575 V; 8 amp

Typical Hours of Operation: 24 hours/day

Estimated Electrical Requirements (KWH/yr): 18,000

VI. SLUDGE DEWATERING

GENERAL INFORMATION

Technology: Membrane Filter Press (side bar design)

No. of Units: 4

Unit Size: 88 - 1200 mm * 1200 mm plates

Plate Material: Rubber coated steel

Date Installed: 1985

Manufacturer: Edwards & Jones

Plate Arrangement:

The plates alternate between diaphragm plates and standard plates.

Operating History:

From 1980 to 1985, 6 belt filter press units were used for sludge dewatering. The belt presses produced a cake with about 20% solids. In 1985, the belt filter presses were replaced with filter presses in an effort to produce a drier cake and reduce auxiliary fuel costs.

Future Operation:

Four additional membrane filter presses will be installed as part of the plant expansion. The new presses will be installed in the existing dewatering building. To make room for the new filter presses, the mothballed belt filter presses were recently removed and sold. Because this building was originally designed for belt filter presses, the building layout is not optimum for filter presses. The four existing filter presses have 88 - 1200 mm plates. Four additional presses of this size would not fit in the existing building. The new filter presses will have 60 - 1500 mm plates. These presses are shorter than the existing presses, but provide a comparable plate area. The installation of filter presses in a building designed for belt filter presses also presented a structural problem. The floor slab was not structurally designed to support the weight of a filter press, so the filter presses must be supported by columns which extend down to the building foundation. The new presses will be overhead bar design to allow the operators easier access to the machine when scraping the plates. Equipment manufacturers are currently bidding on this project.

Centripress technology was considered for this application, but existing installations reported poor solids capture and heavy sidestream flows. For this reason, the centripress was eliminated from further consideration.

2. OPERATING PARAMETERS

Reference attached tables summarizing 1987 operating parameters for the dewatering process.

Average Loading Rate (# cake/day):

The dewatering/incineration system was in operation 276 days in 1987. Most of the 89 days of downtime was due to regular maintenance needs. An unscheduled 3 week shutdown occurred in November when sand leaking into the hot windbox made the system inoperable. During this period, sludge was stored in a reserve secondary clarifier. When normal operation resumed, the stored sludge was paced back into the system. For this reason, two feed rates will be presented; one based on a 276 day/year operation and one based on a 365 day/year operation.

276 day:	35.2 dry ton/day (31.9 dry tonnes/day)
365 day:	26.7 dry ton/day (24.1 dry tonnes/day)

No. Units in Operation:	4 units operate 24 hours/day each day except: (1) 15 hours downtime from Saturday night until Sunday morning (2) 4 hours of maintenance downtime every Wednesday morning
Average Loading Rate (cf/cycle):	3 cubic meter/cycle (106 cf/cycle)
Average Loading Rate (#/cycle):	3 wet tonnes (1 dry tonnes)/cycle 6600 wet # (2200 dry #)/cycle
Typical Cake Thickness:	37 mm
Primary/WAS RATIO:	60/40
Percent Solids of Feed:	3% to 5%
Percent Solids of Cake:	Average 32% (range 28% to 36%)
Polymer Type:	Allied Chemical 757

DUFFIN CREEK DEWATERING SUMMARY
(U.S. Units)

MONTH	INPUT % SOLIDS	OUTPUT % SOLIDS	CAKE % VOLATILES	POLYMER CONSUMED (#/ton)	DRY TONS PRODUCED
JAN	5.2	31.9	38.22	15.7	1006
FEB	4.2	29.4	40.99	17.1	705
MARCH	4.3	30.8	39.11	14.3	874
APRIL	3.6	32.4	39.8	26.8	800
MAY	4.6	34.3	45.67	12.5	671
JUNE	4.6	32.5	40.3	14.9	862
JULY	4.1	31.4	36.94	17.5	774
AUG	5.4	33.2	35.11	15.9	702
SEPT	4.7	31.8	38.51	16.9	998
OCT	4.6	32.6	40.62	18.3	962
NOV	4.4	33.7	41.75	17.5	457
DEC	5.0	34.9	41.81	18.3	1026
TOTAL					9834
AVG	4.56	32.41	39.90	17.11	

Polymer cost is $1.94/#

DUFFIN CREEK DEWATERING SUMMARY
(Metric Units)

MONTH	INPUT % SOLIDS	OUTPUT % SOLIDS	CAKE % VOLATILES	POLYMER CONSUMED (kg/tonne)	DRY TONNES PRODUCED
JAN	5.2	31.9	38.22	7.9	912.2
FEB	4.2	29.4	40.99	8.6	639.3
MARCH	4.3	30.8	39.11	7.2	792.7
APRIL	3.6	32.4	39.8	13.5	725.8
MAY	4.6	34.3	45.67	6.3	608.3
JUNE	4.6	32.5	40.3	7.5	781.8
JULY	4.1	31.4	36.94	8.8	702.1
AUG	5.4	33.2	35.11	8.0	637.0
SEPT	4.7	31.8	38.51	8.5	905.0
OCT	4.6	32.6	40.62	9.2	872.4
NOV	4.4	33.7	41.75	8.8	414.2
DEC	5.0	34.9	41.81	9.2	930.8
TOTAL					8921.6
AVG	4.56	32.41	39.90	8.6	

Polymer cost is $5.15/kg

Polymer Dosage
(#/ton dry solids): Based on 1987 data - Average: 5.4 kg/dry tonne (10.8 #/dry ton)

Frequency of Testing to
Optimize Polymer Dosage: Every 12 hours

Location of Polymer Addition:

The polymer preparation system consists of dry storage, 2 polymer mix tanks, and 2 polymer storage tanks (1500 gallons/each). Polymer is taken from the storage tanks by one of 4 Moyno pumps and injected into a pipe loop from which the filter press feed pump can draw polymer. The filter press feed pumps (6 total with 2 as stand-by units) are positive displacement pumps manufactured by Thomas Willett & Co., Ltd. A measured amount of polymer is injected into the Willett pump on the suction stroke. Polymer that is not injected into the Willett pump continues around the loop and is returned to the polymer storage tanks (see attached figure). The polymer dosage injected by each pump stroke can be varied by adjusting the Moyno pumps to increase the pressure in the polymer feed loop. This "Polymeter System" is supplied by Allied Colloids. This polymer system is able to adjust easily between periods of heavy polymer use and periods of no polymer use and is therefore compatible with a filter press operation. The plant staff believes that the polymer loses some of its effectiveness as it passes through the Willett pump because of shearing. To correct this, the plant staff plans to modify the feed system such that the polymer will be fed on the discharge side of the Willett pump. It is believed that this may save 20% to 25% in polymer costs.

Other Chemicals: None

Rate of Pressure Applied & Pacing of Flow to Filter Press:

Sludge/polymer is pumped at 450 gpm for 70 minutes at a pressure of 120 to 150 psi. Diaphragm air pressure is applied for 40 minutes at 150 psi. Cake unloading takes about 20 minutes for a complete cycle time of 2 hours and 10 minutes.

Cycle Time (Filtration/
Diaphragm Squeeze Time): 2 hours and 10 minutes

Loading Rate: 0.45 lb/sf-day

No. Cycles Per Day: Avg 30
Max 34

Note that 4 units operating 24 hours/day with a cycle time of 2 hour and 10 minute would have the potential to complete 44 cycles/day. With all 4 units operating round the clock,the maximum number of cycles per day at Duffin Creek is 34. It would seem that even though the operation time for each cycle is about 2 hours and 10 minutes, the actual total cycle time is about 3 hours when repair time, preparation time, and other downtime is considered.

Type of Membrane Cloth Used:	Monofilament Polypropylene
Cloth Washing Frequency:	Once per month (takes about 6 hours) Because lime is not used for conditioning, acid wash is not required.
Cloth Life:	9 months
Use of Precoat:	None
Solids Capture:	98+%

3. COST INFORMATION

A. Capital

Facilities Planning Estimate of Capital:	Not Available
Actual Capital Cost:	See attached table.
Cost of Modifications:	See attached table.

The attached table shows the capital cost for the original chemical conditioning and belt filter press installation and the capital cost for the subsequent filter press installation. By updating all costs to a current (September 1988) ENR cost index and substituting the filter press equipment cost for the belt filter press equipment cost, one can develop complete capital cost for each dewatering system. These construction costs are summarized as follows:

System	Capital Cost* ENR = 4535
Belt filter press dewatering/ chemical conditioning	$6,352,000
Filter press dewatering/ chemical conditioning	$7,889,000

*U.S. dollars

Note that the difference between capital costs for the two dewatering systems is not as great as one would expect. The design engineer for these projects informed us that procurement problems and last minute changes in the design lead to significant cost increases in the belt filter press installation.

CAPITAL COSTS - SLUDGE CONDITIONING/DEWATERING

Contract No.	Major Cost Item	Construction/ Purchase Date	Construction ENR	Original Construction Cont (Canadian $1,000)	Updated Construction Cost * (Canadian $1,000)	Updated Construction Cost * (U.S. $1,000)
CHEMICAL CONDITIONING						
9	Gen. Construction	Oct 1978	2851	$843	$1,280	$1,050
	Purchased Equipment:					
9	Polymer Equip	Feb 1978	2681	$137	$232	$190
	Total				$1,512	$1,240
BELT FILTER PRESS INSTALLATION						
9	Gen. Construction	Oct 1978	2851	$2,798	$4,451	$3,650
	Purchased Equipment:					
9	Belt Filter Presses	Aug 1976	2445	$930	$1,725	$1,414
9	Screw Conveyers	July 1978	2821	$188	$302	$248
	Total				$6,478	$5,312
FILTER PRESS MODIFICATION						
22	Gen. Construction	June 1984	4161	$1,404	$1,530	$1,255
	Purchased Equipment:					
22	Filter Presses	Nov 1983	4133	$1,315	$1,443	$1,183
22	Screw Conveyors	March 1984	4118	$246	$271	$222
22	Conveyors	Jan 1985	4172	$36	$39	$32
22	Conveyors	Sept 1982	3878	$191	$223	$183
19/20	Plant Changes	Nov 1982	3918	130	$150	$123
	Total				$3,657	$2,999

* Updated to September 1988 ENR = 4535

Source: This table is based on information presented in the Proctor & Redfern study entitiled:

Development Of A Methodology To Investigate The
Cost Effectiveness Of Various Sludge Management Systems
January 1988

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST CANADIAN	U.S.
Operations Labor	57 hr/day	$373,100	$305,900
Maintenance Labor	14 hr/day*	$ 91,400	$ 74,900
Polymer	10.8 #/dry ton	$245,800	$201,600
Other Chemicals (Odor Control)		$ 8,000	$ 6,600
Electricity	1,166,900 kw-hr/year	$ 52,500	$ 43,200
Materials/Supplies		$143,800	$117,900
Other Purchased Services		$ 40,000	$ 32,800
Total		$954,600	$782,900

*Averaged over a 7 day work week.
The maintenance staff actually works a 5 day work week, averaging 20 hours/day.

Maintenance Concerns:

The press cloth is washed down once per month. No acid wash is required because lime is not used in the operation. The staff uses an automatic washing machine which only needs to be positioned properly. The membrane clothes were replaced for the first time after 10,880 operating hours. Cloth replacement requires 4 maintenance personnal for about 16 hours (64 manhours total).

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of 30 KWH per dry ton (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities) and a consumption of 40 KWH per square foot of building space for lighting, HVAC, and other general building needs.

Estimated Electrical Requirements (kw-hr/year):

Equipment	326,900
Building	840,000
TOTAL	1,166,900

Other Sources of
Energy Consumption: None

VII. CAKE STORAGE/EQUALIZATION

Each filter press discharges into a 3 cubic meter (106 cubic foot) live bottom hopper. Each hopper holds about 1 filter press cycle of sludge. Each furnace is preceeded by a 12 cubic meter (424 cubic foot) storage tank to further equalize the cake feed to the furnaces.

VIII. GRIT, SCREENINGS, AND SCUM DISPOSAL

GRIT DISPOSAL: Landfilled

SCREENINGS DISPOSAL: Landfilled

SCUM AND GREASE DISPOSAL: Scum is added at the digesters and subsequently dewatered and incinerated. Approximately 10,000 gallons per week of scum is processed.

IX. INCINERATION

1. GENERAL INFORMATION

Technology: Fluidized Bed Incineration w/ Hot Wind Box

Start-Up Date: 1981

Manufacturer:
Reactor - Dorr Oliver
Heat Exchanger - Canadian Shack
Waste Heat Boiler - Foster Wheeler
Combustion Air Blower - Spencer 8 stage centrifugal blower

No. of Units: 2 (1 in operation at a time)

System Description:

Each incineration system consists of a hot wind box (HWB) fluidized bed furnace, a heat exchanger, a waste heat boiler, a venturi scrubber, and tray sub-cooler (see figure on page 34). Under normal operation, digester gas is used to fuel the hot windbox which preheats the combustion (fluidizing) air. Flue off-gases from the furnace are passed through a heat exchanger which transfers heat from the hot flue gases to the HWB air feed. The flue gases then pass to a waste heat boiler which produces steam to be used for building heat and to drive the combustion (fluidizing) air blowers. Two auxiliary boilers are available to (1) make up the difference between the plant's heating requirements and the heat production of the waste heat boilers; and (2) provide steam during start-up periods to drive the steam turbines that power the combustion air blowers. If the HWB temperature is so high that preheating of the HWB air feed is not necessary, the hot flue gases can bypass the heat exchanger and be fed directly to the waste heat boiler, increasing steam production.

Reactor Diameter (bottom/top):

Original Diameter:	5600 mm bed/ 6200 mm freeboard (18.4 ft/ 20.3 ft)

The reactor bed diameter has since been reduced by 36 inches by adding a layer of refractory brick around the inside of the furnace.

Future Operation:

It is estimated that one of the existing furnaces has the capacity to handel the sludge generated from a 55 to 60 migd flow (current plant flow is 42 migd). Plans to expand plant capacity to 80 migd are currently in the design phase. As part of the first construction phase, the liquid train and the downstream solids handling processes will be expanded. The installation of a third furnace will be delayed to a second construction phase to be undertaken when plant flows approach 55 migd. The installation of a third furnace will maintain proper redundancy in the incineration system (2 furnaces operating; 1 furnace stand-by).

Sludge Feed System:

As part of the original design, dewatered cake was transferred from the dewatering building to the incineration building by a series of horizontal and vertical screw conveyors. The screw conveying system would transport cake from the filter press discharge hoppers located in the dewatering building to a pair of storage hoppers located in the incineration building. The total conveyor length is about 500 feet. Another screw conveyor would then transfer the cake from the storage hoppers into the furnace. The screw conveying system operated satisfactorily when 20% cake produced by belt filter presses was being transferred to the incineration building. When the belt presses were replaced with filter presses, the screw conveyors had problems transporting the drier (33% solids) cake. Motor burnouts and bearing failures became common. In 1986, the plant staff decided to install a Schwing slurry pump on an experimental basis to evaluate its effectiveness as an alternate cake transfer system.

A Schwing slurry pump capable of pumping slurries with a solids content of up to 80% was installed in the dewatering building. The modified conveying system consists of a screw conveyor that transfers cake from the filter press discharge hoppers to a hopper in the dewatering building which feeds the Schwing pump. The dewatered cake is then pumped about 500 feet from the dewatering buiding to the incineration building. In the original piping layout, the cake was piped directly into the bed of the furnace, bypassing the cake storage tanks in the incineration building. The pumping system experienced some problems during its first year of operation due to high pressures and plugging in the pipeline. The problem with high pressures was alleviated by increasing the diameter of the sludge piping from 6 inch to 8 inch. The plugging problems occurred where the pipeline entered the furnace. Sludge at this point would dry out and clog the pipeline. To alleviate this, the sludge pipeline was modified to discharge into the storage hoppers preceding the furnaces. The existing screw feeder is used to transfer the cake from the hopper to the furnace bed. This system has been operating successfully since February of this year.

Overall, the plant staff has been very pleased with the performance of the Schwing pump. The sludge pumping system is cleaner, less odorous, and more reliable than the screw conveying system. The plant staff plans to purchase two additional Schwing pumps. The two new Schwing pumps will be used to transfer cake from the dewatering building to storage hoppers in the incineration building. The existing Schwing pump will be moved from the dewatering building to the incineration building and used to pump cake from the storage hoppers into the furnace bed. The staff believes that the plugging problems that have occurred in the past will not be a concern with this alignment. The pumping distance from the hopper to the furnace bed will be very short, so the sludge velocity in the pipeline should remain high enough to avoid sludge drying in the pipeline and plugging the pipe. The staff believes that there are both operational and maintenance benefits to pumping directly into the furnace bed. The pipeline is neater and less odorous than the screw conveyor, and the staff believes that the cake burns better when pumped directly to the furnace bed, although no concrete reason for this could be determined.

The Ashbridges Bay WPCF in Toronto also has a Schwing pump that is being used to directly feed dewatered cake to a multiple hearth furnace. The pump has been in operation for about one month.

2. OPERATING PARAMETERS

Reference attached table which summarizes the 1987 operating data.

Operation Schedule:	Normally operate 24 hr/day each day except: (1) 15 hours downtime from Saturday night until Sunday morning (2) 4 hours of maintenance downtime every Wednesday morning
% Solids of Cake Feed:	32%
% Volatiles of Cake Feed:	40%

Average Loading Rate:

The dewatering/incineration system was in operation 276 days in 1987. Most of the 89 days of downtime was due to regular maintenance needs. An unscheduled 3 week shutdown occurred in November when sand leaking into the hot windbox made the system inoperable. During this period, sludge was stored in a reserve secondary clarifier. When normal operation resumed, the stored sludge was paced back into the system. For this reason, two feed rates will be presented; one based on a 276 day/year operation and one based on a 365 day/year operation.

276 day:	35.2 dry ton/day (31.9 dry tonnes/day)
365 day:	26.6 dry ton/day (24.1 dry tonnes/day)

Peak Loading Rate (dry #/day):

The furnaces were originally designed to burn a combination of wastewater sludge and paper mulch. The furnace was sized accordingly with a capacity of 9600 dry #/hour of 30% cake with 70% volatiles. During plant construction, it was decided that paper mulch would not be burned in the furnaces. As a result, the furnaces were grossly oversized for a sludge only operation, leading to excessive fuel use. To decrease the capacity of the reactors, refractory brick has been added to the bed walls to decrease the bed diameter by 36" and several of the tuyeres have been plugged to reduce the air flow to the furnace. The new capacity for each furnace is 40 dry tonnes per day (44 tpd). When sludge production increases in the future, the capacity of the furnace will be increased by removing the extra layer of refractory brick and unplugging several of the tuyeres.

Type of Fuel:

1. Digester gas (22,400 kJ/cubic meter; 600 BTU/cf) for the hot windbox. Digester gas cannot be fed to the furnace burners.

2. No. 2 oil (45325 J/g) for the reactor burners and, if necessary, for the hot wind box. Fuel oil can also be burned in the auxiliary boilers.

3. Natural gas cannot be burned in the reactor or the hot windbox because a feed line was not provided. Natural gas is used as primary fuel for the auxiliary boilers.

   Note: 90 to 95 percent of the fuel consumption is in the hot windbox or auxiliary boiler system. Very little fuel is consumed in the reactor itself.

Freeboard Retention Time:	Greater than 5 seconds
Air System:	Push through system that maintains a 3 psi pressure in reactor and hot wind box. No ID fan.

DUFFIN CREEK INCINERATION SUMMARY
(U.S. Units)

MONTH	NO. DAYS REACTOR OPERATION	REACTOR RUN HOURS	DRY TONS PROCESSED	OIL CONSUMED (gallons)	OIL COST ($/gal)	NATURAL GAS (cf)	GAS COST ($/cf)	ASH PRODUCED (#)	ASH LANDFILL ($/#)	DIGESTER GAS (cf)
JAN	28	419.3	1005	1084	$0.897	6,666,356	$0.004	1,411,608	$0.008	7,930,657
FEB	14	329.45	704	3961	$0.897	7,217,760	$0.004	675,930	$0.008	5,712,082
MARCH	27	537.75	874	10151	$0.897	7,413,438	$0.004	1,235,524	$0.008	6,793,136
APRIL	26	468.85	799	6604	$0.705	5,338,135	$0.003	1,027,388	$0.008	5,040,255
MAY	20	319.55	670	4003	$0.705	1,773,928	$0.003	635,145	$0.008	4,158,094
JUNE	25	494.5	862	961	$0.704	2,502,223	$0.003	1,194,360	$0.008	4,498,881
JULY	24	463	774	3800	$0.705	2,505,825	$0.003	1,041,762	$0.008	4,898,149
AUG	25	348.7	702	6645	$0.705	2,112,313	$0.003	1,346,019	$0.008	3,438,486
SEPT	27	527.2	998	13413	$0.705	2,716,407	$0.003	1,161,824	$0.008	6,825,095
OCT	27	547	961	8906	$0.705	3,742,723	$0.003	1,346,790	$0.008	3,409,281
NOV	10	271.25	456	4882	$0.611	3,482,736	$0.003	517,640	$0.008	5,610,058
DEC	23	568.85	1026	20134	$0.611	6,180,955	$0.003	1,400,186	$0.008	5,015,747
TOTAL	276	5295.4	9832	84544		51,652,799		12,994,175		63,329,922
AVG					$0.737		$0.003		$0.008	

DUFFIN CREEK INCINERATION SUMMARY
(Metric Units)

MONTH	NO. DAYS REACTOR OPERATION	REACTOR RUN HOURS	DRY TONNES PROCESSED	OIL CONSUMED (liters)	OIL COST ($/l)	NATURAL GAS (cu/m)	GAS COST ($/cum)	ASH PRODUCED (kg)	ASH LANDFILL ($/kg)	DIGESTER GAS (cu/m)
JAN	28	419.3	912	4102	$0.289	188770	$0.161	640301	$0.021	224571
FEB	14	329.45	639	14994	$0.289	204384	$0.161	306600	$0.021	161748
MARCH	27	537.75	793	38420	$0.289	209925	$0.161	560430	$0.021	192360
APRIL	26	468.85	725	24996	$0.227	151159	$0.145	466020	$0.021	142724
MAY	20	319.55	608	15150	$0.227	50232	$0.145	288100	$0.021	117744
JUNE	25	494.5	782	3636	$0.227	70855	$0.145	541758	$0.021	127394
JULY	24	463	702	14382	$0.227	70957	$0.145	472540	$0.021	138700
AUG	25	348.7	637	25152	$0.227	59814	$0.145	610550	$0.021	97367
SEPT	27	527.2	905	50768	$0.227	76920	$0.145	527000	$0.021	193265
OCT	27	547	872	33710	$0.227	105982	$0.145	610900	$0.021	96540
NOV	10	271.25	414	18478	$0.197	98620	$0.145	234800	$0.021	158859
DEC	23	568.85	931	76206	$0.197	175025	$0.145	635120	$0.022	142030
TOTAL	276	5295.4	8920	319994		1462643		5894119		1793302
AVG					$0.237		$0.149		$0.021	

Depth of Sandbed: Normal 3 ft
Fluidized 5 ft

No. Units typically in Operation: 1 unit in operation
1 unit in cold stand-by mode

Percent Oxygen in Flue Gas: 4% to 5%

Total Air Feedrate: Original 23,000 cubic meter/hr (actual)
13,540 cfm
Current 10,000 cubic meter/hr (actual)
5,885 cfm

Temperature Profile of Incinerator: See attached sketch.

	C	F
Preheated combustion air	550	1020
Hot Windbox Product Air	900	1650
Bed Temperature	800	1470
Freeboard Temperature	850	1560
Heat Exchanger Product	760	1400
Waste Heat Boiler Steam	270	520
Venturi Inlet Temperature	180	360
Tray Sub-Cooler Inlet	50	122
Stack Exhaust	20	70

Auxiliary Fuel Consumption:

Fuel Oil	9	gal/dry ton
Natural Gas	5,333	cf/dry ton
Digester Gas	6,539	cf/dry ton

3. COST INFORMATION

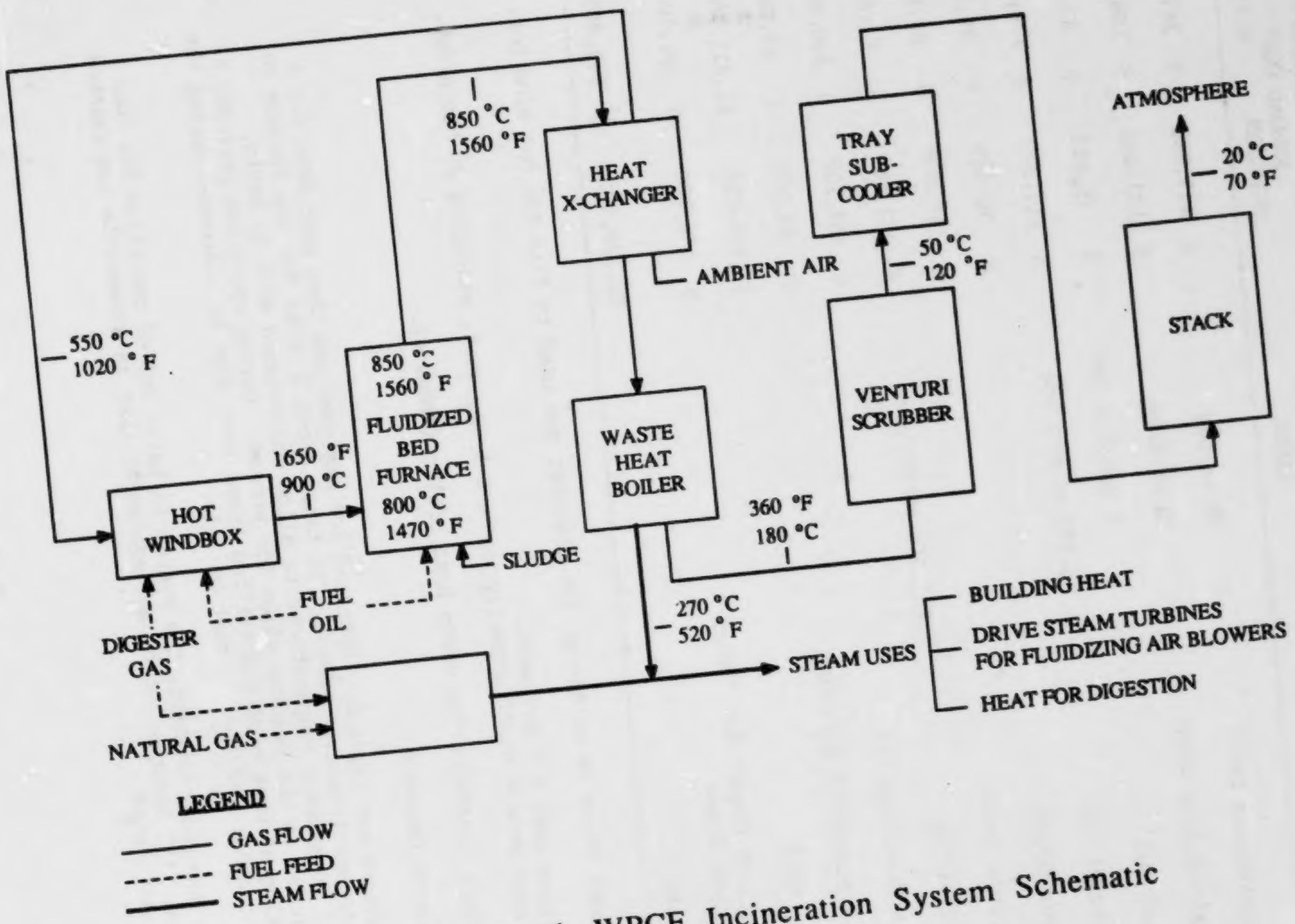
A. Capital

Facilities Plan Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders): See attached tables

Cost of Modifications: None

The cost of the heat recovery system including the waste heat boilers is included in the incineration capital costs. The capital costs for the auxiliary boiler system is included in the boiler facilities capital costs.


550 °C
1020 °F
HOT WINDBOX
1650 °F
900 °C
850 °C
1560 °F
FLUIDIZED BED FURNACE
800 °C
1470 °F
SLUDGE
850 °C
1560 °F
HEAT X-CHANGER
AMBIENT AIR
WASTE HEAT BOILER
360 °F
180 °C
270 °C
520 °F
FUEL OIL
DIGESTER GAS
NATURAL GAS
STEAM USES
BUILDING HEAT
DRIVE STEAM TURBINES FOR FLUIDIZING AIR BLOWERS
HEAT FOR DIGESTION
TRAY SUB-COOLER
50 °C
120 °F
VENTURI SCRUBBER
STACK
20 °C
70 °F
ATMOSPHERE
LEGEND
GAS FLOW
FUEL FEED
STEAM FLOW

Duffin Creek WPCF Incineration System Schematic

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST CANADIAN	U.S.
Operations Labor	68 hr/day	$ 447,800	$ 367,200
Maintenance Labor	20 hr/day*	$ 132,400	$ 108,600
Fuel Oil	9 gal/dry ton	$ 75,800	$ 62,200
Natural Gas	5,333 cf/dry ton	$ 217,900	$ 178,700
Chemicals**		$ 30,000	$ 24,600
Potable Water		$ 110,000	$ 90,200
Electricity	2,253,400 kw-hr/year	$ 101,400	$ 83,400
Materials/Supplies		$ 403,200	$ 330,600
Other Purchased Services		$ 80,000	$ 65,600
Total Cost		$1,598,100	$1,311,100
Operations Credit for "Sale" of Excess Steam		$ 449,700	$ 368,700
Net Cost		$1,148,400	$ 942,400

Note that there is no charge for digester gas used to fire the hot wind box.

*Averaged over a 7 day week.
The maintenance staff actually works a 5 day week, averaging 28 hours/day.

**Chemical treatment for waste heat boiler feedwater.

Maintenance Concerns:

Reactors are typically operated for one year and then shut down for a 2 month maintenance overhaul. It takes about 2 weeks for the furnace to cool to ambient temperatures to allow maintenance work to begin. Manholes in the reactor allow for access. During operation periods, a backlog of work orders detailing items that must be addressed during the maintenance shutdown is kept on file.

Each Wednesday morning, the system is taken out of operation for four hours. All instumentation and equipment that is accessible are checked and calibrated.

CAPITAL COSTS - INCINERATION/HEAT RECOVERY

Contract No.	Major Cost Item	Construction/ Purchase Date	Construction ENR	Original Construction Cost (Canadian $1,000)	Updated Construction Cost * (Canadian $1,000)	Updated Construction Cost * (U.S. $1,000)
INCINERATION						
13	Building	Jan 1979	2,872	$6,326	$9,989	$8,191
15	Equip Foundation	Aug 1978	2,829	$516	$827	$678
18	Incin Stack	March 1979	2,886	$881	$1,384	$1,135
	Purchased Equipment:					
	Incinerators	Aug 1977	2,611	$4,840	$8,407	$6,893
	Screw Conveyors	July 1978	2,821	$771	$1,239	$1,016
19/20	Plant Changes	Sept 1982	3,878	$510	$596	$489
	Total				$22,443	$18,403
BOILER FACILITIES						
15	General Const	Aug 1978	2,829	$2,539	$4,070	$3,337
	Purchased Equipment:					
	Steam Generators	March 1978	2,693	$154	$259	$213
	Boiler Stack	March 1979	2,886	$434	$682	$559
	Total				$5,011	$4,109

* Updated to September 1988 ENR = 4535

Source: This table is based on information presented in the Proctor & Redfern study entitled:

Development Of A Methodology To Investigate The
Cost Effectiveness Of Various Sludge Management Systems
January 1988

A dust problem when removing fly ash from the heat exchanger and boiler was corrected by allowing the ash to accumulate until it reaches a stabilized level.

There have been infrequent failures (one failure each system) of the expansion joints in the heat exchanger.

There have been problems with sand leaking in the tuyeres and accumulating in the HWB. This happened once in 1986 and once in 1987. When this happens, the furnace must be taken off-line and allowed to cool completely before work in the windbox can begin. It takes a minimum of 3 weeks to cool the furnace, remove the sand from the windbox, and put the furnace back into operation. During operation, the amount of sand in the windbox can be monitored through a window in the windbox.

The hot gas damper has been re-designed in each system. The original damper seal was not tight, allowing fly ash to escape from the gas system.

When a furnace is taken off-line, sand that has accumulated in the bed has to be removed to maintain the normal operating sand level. The decrease in air flow resulting from the plugging of several tuyeres has resulted in a significant amount fly ash not being blown from the furnace. An effort has been made recently to maintain air flow levels that are high enough to remove all fly ash from the furnace. This will keep the amount of sand in the furnace at a constant level.

The outer casing of the furnaces have not experienced any corrosion problems. However, some corrosion has occurred on the outer shell of the waste heat boiler. The shell was corroding from the inside out due to cracks in the refractory brick, so some refractory repair was required to curtail the corrosion.

The addition of ferrous sulfate for phosphorus removal has resulted in a scaling problem in the venturi scrubber.

Operation Guidelines:

The operations staff seem very comfortable with fluidized bed incineration system. The goal of the operation is to maintain a bed temperature of about 800 C (1500 F) while using a minimum amount of auxiliary fuel. This bed temperature will produce a flue gas temperature of 800 C to 850 C (1500 to 1560 F), which is high enough to insure complete combustion and eliminate the need for an afterburner.

During normal operation, the operator will monitor the hot windbox temperature, the bed temperature, and the oxygen level in the flue gas to detect changes in the furnace's operation condition. Changes in furnace temperatures can be brought about by a change in the percent solids or the percent volatiles of the sludge feed. The operator can react to these changes in sludge quality by adjusting the air feedrate, adjusting the sludge feedrate, or using auxiliary fuel to fire the reactor burners. For instance, if the sludge feed becomes wetter, the operator can maintain a steady bed temperature by either turning on a reactor burner or cutting back the sludge feed. By manipulating these variables, the operator can control the furnace. Because of the storage and blending areas provided within the solids train, the feed to the furnace is kept fairly constant in terms of sludge quantity and quality. This makes the furnace much easier to operate, as major adjustments in the control variables are rarely required.

The original instrumentation system was designed to be fully automated, but the weigh scale monitoring the feed to the furnace never operated properly so the staff switched to manual control. The staff does plan to upgrade the instrumentation system next year. The upgraded instrumentation system will be automated, using a computer to control the combustion system.

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Typical electrical consumption figures or curves cannot be applied to the Duffin system because the fluidizing air blowers are steam turbine driven. Therefore, equipment electrical consumption will be based upon the connected horsepower of equipment other than the fluidizing air blowers. Electrical consumption for lighting, HVAC, and other general building needs will be estimated based upon a unit consumption of 40 KWH per square foot.

Equipment	Rated HP	Hrs/day Operation	kw-hr/day
Fluidizing (Combustion) Air Blower	600	24	*
Water Pumps for Freeboard Temperature Control		Almost Never	
Purge Air Blower	100	24	1790

*There is no electrical cost for these blowers as they have steam turbine drives.

Estimated Annual Electrical Requirements (KWH/year):

Equipment	653,400
Building	1,600,000
TOTAL	2,253,400

Total Annual Fuel Use (gal/year):

Based on 1987 operating data:

Fuel Oil	319,994 L	84,544 gal
Natural Gas	1,462,643 m	51,652,799 cf
Digester Gas	1,793,302 m	63,329,922 cf**

**Balance of the digester gas that is utilized at the plant site (314,000 cf/day) is consumed in the auxiliary boilers.

Annual Fuel Use For Start-up and Cool-Down Periods (gal/year): Almost none.

Use of Excess steam Generated by WHB:

- building heat throughout the plant
- steam to drive the 485 kw steam turbines that power the fluidizing (combustion) air blowers
- heat for digestion (for details of this system, refer to digestion section)
- as sludge production increases and more waste steam is made available, a generator will be installed to produce electricity for plant use.

Steam Pressure/Temperature: 260 psi
520 F

Steam Production/Distribution: Reference the attached tables.

Steam production is split about 50/50 between the waste heat boilers and the auxillary boilers. About half of the steam produced is used to drive the fluidizing (combustion) air blower and about half is used in the plant heating loop. The heating loop provides building heat to the following 5 areas of the plant:

Area 1	Digester building
Area 2	Administration building
Area 3	Incineration and dewatering buildings
Area 4	Detritor and raw water lift buildings and pump gallery
Area 5	Maintenance and chlorine buildings

A cost credit is taken by the incineration staff for building heat provided to Area 2, Area 4, and Area 5. For in-house bookkeeping purposes, the incineration area pays to operate the waste heat and auxiliary boilers and "sells" the heat product to other areas of the plant. Each month, the cost to produce 1000 kg of steam is determined and used as the unit cost for billing other areas of the plant for steam sales. Area 1 and Area 3 are not billed for heat as these areas are considered part of the incineration system.

The following table summarizes the 1987 steam distribution to the five areas and the amount charged for this steam (see attached tables for more detailed breakdown):

AREA	% TOTAL STEAM	COST (CANADIAN $)	COST (U.S. $)
1	38	341,738	280,225
2	10	89,929	73,740
3	12	107,917	88,490
4	22	197,848	162,235
5	18	161,875	132,740
TOTAL	100	899,300	737,430

The heat provided to Areas 2, 4, and 5 results in a cost credit to the incineration system of $449,652 Canadian ($368,715 U.S.).

The O&M cost table presented on page 26 shows an annual energy cost (fuel oil, natural gas, and electricity) of $395,100 Canadian ($324,300 U.S.) for the incineration system. The total value of the energy produced by the incineration system is taken to be $899,300 by the plant staff. Based on these in-house econcomics, it would appear that the incineration system is a net energy producer with a net energy value of $504,200 Canadian.

However, this evaluation can be misleading because the unit cost used for steam sales is based on the cost to produce the steam and may not reflect the true energy value of the steam. For this reason, the incineration system was evaluated in terms of BTUs of energy input and BTUs of energy output to determine the true net energy consumption of the system (Reference the attached schematic). The BTU conversion factors used in this evaluation are as follows:

Fuel Oil	138,000 BTU/gal
Natural Gas	1,000 BTU/cubic foot
Digester Gas	600 BTU/cubic foot
Steam*	1,572 BTU/# steam
Electricity**	10,000 BTU/kw-hr

*The energy value of 260 psi steam at 520 F is 1273 BTU/cf. A typical boiler is approximately 90% efficient in the combustion process and approximately 90% efficient in converting this heat energy to steam, resulting in an overall efficiency of 81%. Therefore, an energy value of 1572 BTU/# steam (1273/.81) was used in this evaluation. This is the amount of energy required to produce 260 psi, 520 F steam if an auxiliary boiler is used.

**This figure accounts for inefficiency in the production of electricity. It is assumed that electrical production is about 38% efficient.

An incineration system's energy efficiency is generally measured by its consumption of auxiliary fuel to sustain the combustion process. This is difficult to measure at Duffin Creek because here the incineration system is taken to be the furnace, the waste heat boilers, and the auxiliary boilers. This system provides steam to drive turbines and to feed the plant heating loop. It is impossible to break out the exact amount of fuel consumed by the furnace itself. The system must be evaluated as a whole, with the energy input to the system compared to the energy output.

The system was evaluated for 3 scenarios. The scenarios vary in terms of how the energy input to the system is defined.

Scenario 1: Only fuel oil and natural gas are considered energy inputs to the system. Digester gas is considered a "free" source of energy from the solids train. The free use of digester gas is the energy credit that balances the loss of volatiles in the digesters. Electricity is not considered.

Scenario 2: Fuel oil, natural gas, and electricity are considered energy inputs to the system. Digester gas is again considered a "free" source of energy.

Scenario 3: Fuel oil, natural gas, electricity, and digester gas are all considered energy inputs to the system.

In all cases, the energy output from the system is taken to be the pounds of steam provided to the plant heating loop. Steam used to drive the steam turbines for the fluidizing air blower is not considered an energy output, as this energy is consumed within the incineration system. All consumption values are based on 1987 data.

The results of the evaluation are as follows:

Scenario 1

Energy Input (1,000,000 BTU/Year)	
Fuel Oil	11,700
Natural Gas	51,600
TOTAL	63,300

Energy Output (1,000,000 BTU/Year)	
Steam to Heating Loop	61,000

Net Consumption

2,300 million BTU/year
equivalent to 1.7 gal/dry ton of sludge

Scenario 2

Energy Input (1,000,000 BTU/Year)

Fuel Oil	11,700
Natural Gas	51,600
Electricity	22,500
TOTAL	85,800

Energy Output (1,000,000 BTU/Year)

Steam to Heating Loop	61,000

Net Consumption

24,800 million BTU/year
equivalent to 18.3 gal/dry ton of sludge

Scenario 3

Energy Input (1,000,000 BTU/Year)

Fuel Oil	11,700
Natural Gas	51,600
Electricity	22,500
Digester Gas	38,000
TOTAL	123,800

Energy Output (1,000,000 BTU/Year)

Steam to Heating Loop	61,000

Net Consumption

62,800 million BTU/year
equivalent to 46.3 gal/dry ton of sludge

This evaluation shows that the energy efficiency of an incineration system depends to a great extent on how one defines the energy input to the system. If one considers auxiliary fuel use (fuel oil or natural gas) to be the primary measure of the efficiency of an incineration process and one considers digester gas as a "free" source of fuel provided by the solids train, then the Duffin incineration system comes very close to being a self-sustaining energy system (scenario 1). As the definition of energy input is expanded, the net energy consumption increases accordingly (scenarios 2 and 3).

It should be noted that the net energy consumption of the system is likely to decline in the future as sludge production increases and utilization of the digester gas improves. Increased sludge production will result in

STEAM PRODUCTION/DISTRIBUTION
(METRIC UNITS)

MONTH	STEAM PRODUCTION (KG)			STEAM DISTRIBUTION			
	AUXILIARY BOILER	WASTE HEAT BOILER	TOTAL STEAM	FLUIDIZING AIR TURBINE KG	FLUIDIZING AIR TURBINE $	HEATING LOOP KG	HEATING LOOP $
JAN	1,885,770	1,959,290	3,845,060	1,593,340	93,386	2,036,150	119,339
FEB	2,217,670	1,247,840	3,465,510	1,251,910	82,087	2,213,600	145,145
MARCH	2,104,328	2,171,800	4,276,128	2,043,450	149,803	2,232,678	163,675
APRIL	1,584,600	1,233,720	2,818,320	1,781,630	82,712	1,036,690	48,128
MAY	1,327,850	947,500	2,275,350	1,214,290	57,350	1,061,060	50,115
JUNE	778,150	1,647,700	2,425,850	1,879,100	93,992	546,750	27,351
JULY	1,063,870	1,326,370	2,390,240	1,759,400	82,498	630,840	29,581
AUG	893,070	1,364,830	2,257,900	1,325,060	68,532	932,840	48,248
SEPT	1,174,110	2,307,400	3,481,510	2,003,360	79,793	1,478,150	58,874
OCT	1,429,450	1,932,040	3,361,490	2,078,600	87,259	1,282,890	53,862
NOV	2,379,250	792,250	3,171,500	1,030,750	34,416	2,140,750	71,474
DEC	2,649,900	1,524,090	4,173,990	2,161,630	89,707	2,012,360	83,518
TOTAL	19,488,018	18,454,830	37,942,848	20,122,520	1,001,535	17,604,758	899,310

* Not Available

STEAM PRODUCTION/DISTRIBUTION
(U.S. UNITS)

MONTH	STEAM PRODUCTION (#)			STEAM DISTRIBUTION			
	AUXILIARY BOILER	WASTE HEAT BOILER	TOTAL STEAM	FLUIDIZING AIR TURBINE #	FLUIDIZING AIR TURBINE $	HEATING LOOP #	HEATING LOOP $
JAN	4,157,369	4,319,451	8,476,819	3,512,677	76,577	4,488,896	97,858
FEB	4,889,075	2,750,988	7,640,063	2,759,961	67,311	4,880,103	119,019
MARCH	4,639,202	4,787,950	9,427,152	4,504,990	122,838	4,922,162	134,214
APRIL	3,493,409	2,719,859	6,213,268	3,927,781	67,824	2,285,487	39,465
MAY	2,927,378	2,088,859	5,016,237	2,677,024	47,027	2,339,213	41,094
JUNE	1,715,509	3,632,519	5,348,029	4,142,664	77,073	1,205,365	22,428
JULY	2,345,408	2,924,115	5,269,523	3,878,773	67,648	1,390,750	24,256
AUG	1,968,862	3,008,904	4,977,766	2,921,227	56,196	2,056,539	39,563
SEPT	2,588,443	5,086,894	7,675,337	4,416,607	65,430	3,258,729	48,277
OCT	3,151,365	4,259,375	7,410,741	4,582,482	71,552	2,828,259	44,167
NOV	5,245,295	1,746,594	6,991,889	2,272,391	28,221	4,719,497	58,609
DEC	5,841,970	3,360,009	9,201,978	4,765,529	73,560	4,436,449	68,485
TOTAL	42,963,284	40,685,518	83,648,803	44,362,108	821,259	38,811,449	737,434

* Not Available

STEAM ALLOCATION (KG STEAM)

Building Area	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	% Total
Digester Building	773,737	841,168	848,418	393,942	403,203	207,765	239,719	354,479	561,697	487,498	813,485	764,697	6,689,808	0.38
Administration Building	203,615	221,360	223,268	103,669	106,106	54,675	63,084	93,284	147,815	128,289	214,075	201,236	1,760,476	0.10
Incineration & Dewatering Buildings	244,338	265,632	267,921	124,403	127,327	65,610	75,701	111,941	177,378	153,947	256,890	241,483	2,112,571	0.12
Detritor & Raw Lift Buildings & Pump Gallery	447,953	486,992	491,189	228,072	233,433	120,285	138,785	205,225	325,193	282,236	470,965	442,719	3,873,047	0.22
Maintenance & Chlorine Buildings	366,507	398,448	401,882	186,604	190,991	98,415	113,551	167,911	266,067	230,920	385,335	362,225	3,168,856	0.18
Total	2,036,150	2,213,600	2,232,678	1,036,690	1,061,060	546,750	630,840	932,840	1,478,150	1,282,890	2,140,750	2,012,360	17,604,758	1.00

STEAM COST ALLOCATION
(U.S. $)

Building Area	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Digester Building	$37,186	$45.227	$51,001	$14,997	$15,616	$8,522	$9,218	$15,034	$18,345	$16,784	$22,271	$26,024	$280,225
* Administration Building	$9,786	$11.901	$13,421	$3,947	$4,109	$2,243	$2,426	$3,956	$4,827	$4,417	$5,861	$6,849	$73,742
Incineration & Dewatering Buildings	$11,743	$14,282	$16,106	$4,736	$4,931	$2,691	$2,911	$4,749	$5,793	$5,300	$7,033	$8,218	$88,492
* Detritor & Raw Lift Building & Pump Gallery	$21,529	$26,184	$29,527	$8,682	$9,041	$4,934	$5,337	$8,704	$10,621	$9,717	$12,894	$15,067	$162,235
* Maintenance & Chlorine Buildings	$17,614	$21,423	$24,158	$7,104	$7,397	$4,037	$4,367	$7,122	$8,690	$7,950	$10,549	$12,327	$132,738
Total Cost	$97,859	$119,018	$134,212	$39,465	$41,094	$22,427	$24,257	$39,564	$48,276	$44,167	$58,608	$68,485	$737,432
Total Cost Credit	$48,929	$59,509	$67,106	$19,732	$20,547	$11,214	$12,129	$19,783	$24,138	$22,083	$29,304	$34,242	$368,715

* Steam provided to these areas is recorded as a cost credit to the incineration system.

STEAM COST ALLOCATION
(Canadian $)

Building Area	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Digester Building	$45,349	$55,155	$62,196	$18,289	$19,044	$10,393	$11,241	$18,334	$22,372	$20,468	$27,160	$31,737	$341,738
* Administration Building	$11,934	$14,514	$16,367	$4,813	$5,011	$2,735	$2,958	$4,825	$5,887	$5,386	$7,147	$8,352	$89,929
Incineration & Dewatering Buildings	$14,321	$17,417	$19,641	$5,775	$6,014	$3,282	$3,550	$5,790	$7,065	$6,463	$8,577	$10,022	$107,917
* Detritor & Raw Lift Building & Pump Gallery	$26,255	$31,932	$36,008	$10,588	$11,025	$6,017	$6,508	$10,615	$12,952	$11,850	$15,724	$18,374	$197,848
* Maintenance & Chlorine Buildings	$21,481	$26,126	$29,461	$8,663	$9,021	$4,923	$5,325	$8,685	$10,597	$9,695	$12,865	$15,033	$161,875
Total Cost	$119,340	$145,144	$163,673	$48,128	$50,115	$27,350	$29,582	$48,249	$58,873	$53,862	$71,473	$83,518	$899,307
Total Cost Credit	$59,670	$72,572	$81,836	$24,064	$25,057	$13,675	$14,791	$24,125	$29,436	$26,931	$35,736	$41,759	$449,652

* Steam provided to these areas is recorded as a cost credit to the incineration system.

greater steam production from the waste heat boiler. This will reduce auxiliary boiler use and therefore reduce the consumption of natural gas and fuel oil. Increased utilization of digester gas will also reduce the amount of auxiliary fuel consumed in the auxiliary boilers. Although this increase in steam production (energy output) will be balanced somewhat by an increase in energy required to burn the additional sludge (energy input), it is believed that the growth in energy output will exceed the growth in energy input.

X. AIR EMISSIONS CONTROL

1. GENERAL INFORMATION

Applicable Air Emissions Standards: Ontario Standards

Technology: Venturi wet scrubber and cooling tower arranged in series with a pressure drop of 7 inches w.c. No afterburner.

Scrubber Manufacturer: Ducon-Mikropul Limited

Date of Last Emissions Test:

An extensive emissions test was performed about 2 years ago. Although the Ministry of the Environment has not yet released an official report summarizing the test results, the staff has been informed informally that all emissions standards were met easily.

Stack height: 209 ft

Scrubber Water Treatment: Returned to head of plant

Scrubber Water Characteristics (Q,TSS,BOD): Not Measured

XI. ASH DISPOSAL

1. GENERAL INFORMATION

Technology:

The original dry ash handling system has been mothballed. As part of the existing system, wet ash is thickened in a gravity thickener, the thickened ash is dewatered to about 60% solids using a vacuum filter, and the dewatered ash is landfilled. An outside contractor is responsible for hauling and disposing of the thickened ash.

Location of Landfill: Off-site at a landfill in Pickering

DUFFIN CREEK - REGULATION 308 ASSESSMENT (10)

			Current Reg. 308				Proposed Reg. 308			
Element	Avg. Conc. Over 4 hr (ug/m3)	Emission Rate (g/sec)	Calc'd Max. Conc (ug/m3)	Regulated Conc @POI 1/2 hr Avg (ug/m3)	% of Regulated Maximum	Element Regulated As	Calc'd Max. Conc (ug/m3)	Regulated Ambient Air Std Conc (ug/m3)	Avg Time	% of Regulated Maximum
Silver	4	1.43X10-5	1.08X10-4	3	0.004		3.23X10-4	1	24 hr	0.033
Aluminum	10,374	3.82X10-2	2.83X10-1	-	-	oxide	8.60X10-1	33	24 hr	2.037
Arsenic	1	3.62X10-6	2.69X10-5	75	0.000		8.13X10-5	0.3	24 hr	0.027
Boron	77	2.78X10-4	2.07X10-3	100	0.002		6.26X10-3	35	24 hr	0.018
Barium	252	9.11X10-4	6.79X10-3	-	-		2.03X10-2	10	24 hr	0.203
Beryllium	0	0.00	0.00	0.03	0.000		0.00	0.01	24 hr	0.000
Calcium	13,927	3.76X10-2	4.29X10-1	27	1.589	hydroxide	1.30	13.5	24 hr	9.396
						oxide		10	24 hr	12.933
Cadmium	13	4.70X10-5	3.50X10-4	5	0.007		1.06X10-3	2	24 hr	0.053
Cobalt	2	7.23X10-6	5.39X10-5	-	-		1.63X10-4	-	-	-
Chromium	258	9.33X10-4	6.93X10-3	30	0.023		2.10X10-2	1.5	24 hr	1.399
Copper	288	1.04X10-3	7.76X10-3	100	0.008		2.34X10-2	50	24 hr	0.047
Iron	2,793	1.01X10-2	7.33X10-2	10	0.733		2.27X10-1	4	24 hr	5.686
Potassium	1,037	3.82X10-3	2.83X10-2	-	-	hydroxide	8.60X10-2	14	24 hr	0.614
Magnesium	2,008	7.26X10-3	5.41X10-2	100	0.054	oxide	1.63X10-1	100	24 hr	0.163
Manganese	77	2.78X10-4	2.07X10-3	100	0.002		6.26X10-3	10	24 hr	0.063
Molybdenum	1	3.62X10-6	2.69X10-5	-	-		8.13X10-5	-	-	-
Sodium	3,362	1.29X10-2	9.59X10-2	-	-	hydroxide	2.90X10-1	10	24 hr	2.897
Nickel	112	4.05X10-4	3.02X10-3	5	0.060	reviewing	9.11X10-3	2	24 hr	0.455
Phosphorus	7,407	2.68X10-2	1.99X10-1	100	0.199	P205	6.02X10-1	100	24 hr	0.602
Lead	114	4.12X10-4	3.07X10-3	10	0.031		9.27X10-3	5	24 hr	0.185
								2	30 d	0.464
Silicon	2,014	7.28X10-3	5.42X10-2	-	-	silica-	1.64X10-1	5	24 hr	3.276
Strontium	68	2.46X10-4	1.83X10-3	-	-		5.55X10-3	-	-	-
Thorium	0	0.00	0.00	-	-		0.00	-	-	-
Titanium	130	4.70X10-4	3.50X10-3	100	0.004		1.06X10-2	35	24 hr	0.030
Vanadium	4	1.43X10-5	1.08X10-4	5	0.002		3.23X10-4	2	24 hr	0.016
Zinc	496	1.79X10-3	1.34X10-2	100	0.013		4.05X10-2	100	24 hr	0.040
Zirconium	2	7.23X10-6	5.39X10-5	-	-		1.63X10-4	-	-	-
Particulate	116,833	4.23X10-1	3.15	100	3.147	< 44	9.50	120	24 hr	7.919
						microns		60	1 yr	15.838
Mercury	633	1.50X10-3	1.12X10-2	5	0.224		3.38X10-2	2	24 hr	1.689

Total Annual Volume of Ash Landfilled:	About 6,000 tonnes (6,600 tons) per year	

2. COST INFORMATION

A. Capital

Cost of Trucking:	$54/load Canadian $44/load U.S.	1 load = 10 tonnes = 11 tons
Tipping Fee at Landfill:	$22/tonne Canadian $16.4/ton U.S.	

B. O&M

ITEM	CONSUMPTION LEVEL	ANNUAL COST CANADIAN	U.S.
Operations Labor	2 hr/day	$ 13,100	$ 10,700
Maintenance Labor	1 hr/day	$ 6,600	$ 5,400
Trucking	6,600 tons/year	$ 32,400	$ 26,600
Tipping Fee	6,600 tons/year	$132,000	$108,200
Total		$184,100	$150,900

XII. ODOR CONTROL

For each solids handling process, provide the means of odor control used and provide the appropriate capital and O&M information.

			OPERATIONS & MAINTENANCE COSTS			
PROCESS	CONTROL TECHNOLOGY	CAPITAL COST	LABOR COST	CHEMICAL COST	ELECTRIC COST	MATERIALS COST
Sludge Storage	none					
Dewatering	aerosol spray masking agent	$5,000	$4,000	$8,000	Nil	$0
Incineration Building	none					

XIII. MANPOWER ALLOCATION

The plant staff at Duffin Creek is divided into three distinct groups, each with a division supervisor (see attached schematic):

1. A dewatering/incineration staff that is responsible for the operations and maintenance of the dewatering and incineration systems. The sludge holding tanks and the chemical conditioning system are considered part of the dewatering system.

2. A plant operations staff that is responsible for the operation of all unit processes other than the dewatering and incineration processes (liquid train and sludge digestion).

3. A plant maintenance staff that is responsible for the maintenance of all unit processes other than the dewatering and incineration processes.

The dewatering/incineration staff handles all maintenance for the dewatering and incineration systems except for instrumentation and electrical work. When electrical or instrumentation maintenance is required in the dewatering or incineration areas, the dewatering/incineration staff borrows an instrumentation technician or a electrician from the plant operations staff. It is estimated by plant supervisors that a electrician and an instrumentation technician from the plant maintenance staff each spend about half their time (26 weeks/year) in the dewatering and incineration areas. In addition, general plant housekeeping duties (sweeping, general cleaning, etc.) are contracted out to an outside firm.

The dewatering/incineration staff consists of 27 operators and maintenance personnel. Operations personnel are divided into four shifts working on a rotation program of 12 hour shifts. Each operator averages a 40 hour work week. Maintenance personnel work a conventional 5 day, 40 hour week. The 27 person staff is divided up as follows:

1. Dewatering Staff

   A. Operations

2 operators/shift * 4 shifts =	8 operators
on day shift only, have:	1 foreman
	1 floater
Total	10 operators

   B. Maintenance

   1 shift/day with 2 maintenance personnel assigned to the dewatering area

2. Incineration Staff

A. Operations

2 operators/shift * 4 shifts =	8 operators
on day shift only, have:	3 floaters
	1 clerk
Total	12 operators

B. Maintenance

1 shift/day with 3 maintenance personnel assigned to the incineration area

3. Total

A. Operations

total of 22 operators

B. Maintenance

total of 5 maintenance personnel

XIV. COST SUMMARY TABLES

The following tables attempt to (1) estimate a reasonable construction cost for the existing Duffin Creek solids handling facilities in 1988 dollars; (2) convert the construction cost to an annual cost; and (3) present a total annual cost (capital plus O&M) for each unit process. Capital costs have been estimated by updating the original construction costs to 1988 dollars using the Engineering News Record (ENR) cost index. Operation and maintenance costs have been summarized based on the tables presented earlier in this report.

It should be emphasized that construction costs for such a facility are very difficult to estimate and, even if estimated accurately, are very difficult to use in comparison with other facilities. In reviewing these costs, the reader should consider the following comments:

- Building prices for two similiar facilities can be very different depending on such site-specific factors such as depth of ledge, local materials costs, site constraints, construction market conditions, or other construction considerations.

- The amount of reserve capacity built into a facility can significantly affect construction costs. The amount of reserve capacity allowed for during design can depend on several factors such as site-specific constraints, plans for future expansion or growth, and the design consultant's philosophy concerning system redundancy.

DUFFIN CREEK WPCF
CONSTRUCTION COSTS
(U.S. DOLLARS)

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4535)	AMORTIZED CAPITAL COST
Sludge Digestion		
-structures	$4,235,000	$355,100
-equipment	$2,340,000	$238,300
-total	$6,575,000	$593,400
Sludge Conditioning/Dewatering		
-structures	$5,883,000	$493,300
-equipment	$2,006,000	$204,300
-total	$7,889,000	$697,600
Sludge Incineration		
-structures	$13,341,000	$1,118,800
-equipment	$9,170,000	$934,000
-total	$22,511,000	$2,052,800

DUFFIN CREEK WPCP
ANNUAL COSTS FOR SOLIDS
HANDLING PROCESSES
(U.S. DOLLARS)

PROCESS	AMORTIZED CAPITAL	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS	PURCHASED SERVICES	TOTAL ANNUAL COST	COST CREDIT	NET ANNUAL COST	% TOTAL ANNUAL COST	CAPITAL COST $/DRY TON (3)	O&M COST $/DRY TON	TOTAL COST $/DRY TON
Sludge Pumping	(1)	$0	$600	$0	$0	$3	$0	$606	$0	$606	0.01%	0	0.08	$0.08
Sludge Digestion	$593,400	$49,700	$33,900	$0	$0	$7,000	$11,662	$716,200	$0	$716,200	13.31%	54.13	11.88	$66.07
Sludge Dewatering	$697,600	$300,000	$43,200	$0	$288,300	$117,300	$32,600	$1,480,500	$0	$1,480,500	27.76%	63.71	79.63	$143.34
Sludge Incineration	$2,052,000	$475,000	$83,400	$240,500	$24,600	$420,800	$65,600	$3,063,300	($268,700)	$2,795,200	56.12%	187.47	95.85	$283.32
Ash Disposal	(2)	$16,100	$0	$0	$0	$26,000	$108,200	$150,900	$0	$150,900	2.83%	0	15.35	$15.35
TOTAL	$3,343,000	$913,400	$181,300	$240,500	$232,800	$572,700	$221,466	$5,706,300	($368,700)	$5,337,600	100.00%	$305	$203	$504

(1) Included in unit process capital costs.

(2) Included in incineration capital costs.

(3) Based on system capacity of 30 dry tpd.

NOTE: All per ton costs based on 1987 consumption records and 1987 sludge production (9032 tons/year of dewatered cake).

All costs presented in U.S. dollars and based on September 1988 cost indices.

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In converting the estimated construction cost to an annual cost, it was assumed that all structures would have a useful life of 40 years and all equipment would have a useful life of 20 year life. Capital costs for the filter press dewatering system only were included in these tables.

XV. SUMMARY OF ENERGY REQUIREMENTS

The following table summarizes energy consumption requirements for each unit process. To allow a true comparison of energy efficiency with other facilities, each form of energy consumption (electricity, fuel oil, natural gas, digester gas, steam) has been converted to a common unit (BTUs). The energy consumption of each unit process has been determined based on tables presented earlier in this report. Energy credits have been accounted for where applicable. The net energy consumption consumption for each unit process and for the system as a whole has been determined and expressed on a per ton basis.

Note that the freeboard temperature in the fluidized bed furnace is over 1500 F. Many multiple-hearth incineration facilities (i.e. Upper Blackstone WPCF) currently operate with a flue gas temperature of 800-1000 F. If more stringent air emissions regulations are imposed in the future, the installation of an afterburner may be required at all multiple-hearth facilities to control the possible products of incomplete combustion. Operation of an afterburner is very costly in terms of auxiliary fuel use. However, the fluidized bed furnace normally operates with a flue gas temperature in excess of 1500 F, thereby insuring complete combustion and eliminating the need for an afterburner. For this reason, when comparing fluidized bed facilities vs multiple-hearth facilities in terms of economy and energy consumption, the economic and energy impacts of an afterburner for the muliple-hearth facility should be included in the comparison.

XVI. LESSONS LEARNED

Operating experience at the Duffin Creek Water Pollution Control Facility offers several insights into fuel-efficient incinerator operation.

Experience at Duffin Creek demonstrates that digestion can be part of a successful incineration process. The digesters serve several functions. The digestion process provides sludge storage within the solids train, offers an excellent means of incorporating scum into the sludge, produces a sludge that can be dewatered without odor problems, and produces an end product that can be used as a fuel source for the incinerator. These factors offset the negative impacts of the digestion process, chiefly the destruction of combustibles prior to the incineration process.

Experience at Duffin Creek shows that the means of conveying the sludge to the incinerator is a critical part of the solids train that should not be overlooked in design. The conveyance system must be dependable and have the capacity to meet the system's demands. Breakdowns in the conveyance system results in incinerator shut-down and start-up periods that require

[illegible] CREEK WPCP
ENERGY REQUIREMENTS FOR SOLIDS
HANDLING PROCESSES

PROCESS	ELECTRICITY (KW-HR/YEAR) Building	Equip	Total	ENERGY CONSUMPTION FUEL OIL (GAL/YEAR)	NATURAL GAS (CF/YEAR)	DIGESTER GAS (CF/YEAR)	STEAM (HEAT) (#/YEAR)	TOTAL BTUs (CONSUMED)	ENERGY CREDIT DIGESTER GAS (CF/YEAR)	STEAM (#/YEAR)	TOTAL BTU CREDIT	NET BTU CONSUMPTION	% TOTAL BTU CONSUMPTION	BTU/DRY TON *
Sludge Pumping	--	17,000	17,000	0	0	0	0	170,000,000	0	0	0	170,000,000	0.58%	17,517
Sludge Digestion	25,000	1,431,200	1,456,200	0	0	0	14,748,350	37,746,406,120	150,810,000	0	90,500,000,000	(52,753,593,880)	-179.15%	(5,435,713)
Sludge Storage	--	10,000	10,000	0	0	0	0	100,000,000	0	0	0	100,000,000	0.34%	10,304
Sludge Dewatering	840,000	326,900	1,166,900	0	0	0	2,328,687	15,329,695,964	0	0	0	15,329,695,964	52.06%	1,579,567
Sludge Incineration	1,600,000	653,400	2,253,400	84,544	51,652,799	63,329,522	2,328,687	127,512,520,164	0	38,811,443	61,000,000,000	66,512,520,164	225.87%	6,853,428
TOTAL	2,465,000	2,447,300	4,912,300	84,544	51,652,799	63,329,522	19,405,724	180,946,622,328	150,810,000	38,811,443	151,500,000,000	29,446,622,328	100.00%	3,034,170

NOTE:
Electricity 10,000 BTU/kw-hr
Steam 1572 BTU/#
Digester Gas 600 BTU/cf
Fuel Oil 138,000 BTU/gal
Natural Gas 1000 BTU/cf

* Based on 1987 sludge production (9705 tons)

auxiliary fuel use. Cement-type pumps are a viable option to belt and screw conveyors.

Sludge storage and equalization throughout the solids train is essential to fuel-efficient incineration. This storage buffers the furnace against changes in sludge quantity and quality.

In addition to sludge storage, the heat storage in the fluidized bed provides additional protection against system upsets. This heat storage allows operators at Duffin Creek to burn 18 hours per day at an optimum feed rate rather than 24 hours per day at a light feed rate. The heat storage helps make the success of the incineration system less dependent on the success of the preceding treatment processes.

A fluidized-bed furnace is easier to operate and control than a multiple-hearth furnace. There are fewer operational parameters to monitor and the heat sink built into the furnace makes it less susceptible to upsets. Operators seem very comfortable with the system.

APPENDIX D
CRANSTON
WATER POLLUTION CONTROL FACILITY

I. GENERAL INFORMATION

Address:	Cranston WPCF 140 Pettaconsett Avenue Cranston, Rhode Island 02920
Phone Number:	(401) 467-5511 (401) 461-1000 ext. 2190
Contact:	Donald Benz Administrative Engineer/Acting Superintendent
Design Engineer:	Universal Engineering 100 Boylston Street Boston, MA Project Engineer: Dave Press
Year Began Operation:	Upgrade to the dewatering and thickening systems complete in 1985. The upgraded incineration system went on-line in 1986.
Design Average Flow:	23 mgd
Design Peak Flow:	Max Hour 44 mgd Max Day 36 mgd
Current Average flow:	10 mgd (includes 35,000 gpd of septage)
Current Peak Flow:	23 mgd
Average Influent BOD:	133 mg/l (1987)
Average Influent TSS:	165 mg/l (1987)
Average Effluent BOD:	17 mg/l (1987)
Average Effluent TSS:	10 mg/l (1987)
Permitted Limits:	
BOD, monthly	30 mg/l
TSS, monthly	30 mg/l
Fecal Coliform, monthly	200/100 ml
Ammonia	—

Plant Overview:

Treatment processes in the liquid train include screening, grit removal with detritors, primary settling, biological secondary treatment utilizing the activated sludge process, secondary settling, and chlorination. The solids handling train consists of separate thickening of the primary and waste activated sludges using gravity thickening (primary) and dissolved air flotation (DAF) thickening (waste activated), sludge blending, dewatering with fixed-volume filter presses, and multiple-hearth incineration. Three digesters from the original treatment facility are now used as sludge holding tanks. These tanks can be used to hold sludge during periods when the dewatering/incineration system is off-line.

Operating History:

Plant operations at the Cranston Facility are currently in a state of transition. At the time of our first visit in September 1987, the gravity thickeners and the DAF thickeners were not on-line. Waste activated sludge was returned from the secondary clarifiers to the primary clarifiers and co-settled with the primary sludge. The thickening units were bypassed and sludge was sent directly to the sludge blend tank and the subsequent filter press dewatering process.

In June of 1988, a new administrative engineer took over the facility and implemented several process changes. Under normal operating conditions, waste activated sludge is no longer returned to the primary clarifiers to be co-settled. The DAF and gravity thickeners were put back on-line so that the primary and waste activated sludges could be settled and thickened separately. Since July 1988, the facility has operated primarily in this separate thickening mode, although equipment breakdowns have forced the staff to operate in the co-settling mode at times. The new administrative engineer has also implemented an aggressive maintenance program aimed at getting broken equipment back into operable condition.

The plant is currently understaffed. The plant staff is budgeted for 6 maintenance personnel, 12 plant operators, 10 solids processing operators, and 4 senior operators. This staff is responsible for the operation and maintenance of the wastewater treatment facility and all pump stations in the collection system. Plant management recognizes that there is a staffing problem and is currently exploring the possibility of going to a private contract operations arrangement.

The solids handling facilities at Cranston are currently operating with a significant amount of excess capacity. As a result, the incineration process must operate on a five day cycle rather than a more fuel efficient seven day operation. However, two developments are taking place that may significantly increase the quantity of sludge to be processed in the near future. One relates to the level of treatment provided at the Cranston facility. The 1985 plant upgrade was designed to provide tertiary level treatment. Due to a lack of available grant funding, the tertiary treatment processes were not constructed. However, the plant staff believes that the State regulatory agancies will require that tertiary level treatment be implemented in the near future. Tertiary treatment processes would produce a significant amount of additional sludge.

A second development relates to the State policies regarding sludge landfilling. State regulatory agencies are in the process of imposing severe restrictions on the quantities of sludge that may be landfilled in Rhode Island. As a result, many communities that now landfill their sludge will be searching for new disposal alternatives, one of which would be to transport their sludge to Cranston to be incinerated. There is the possibility that the Cranston WPCF could become a regional sludge processing facility.

Attached is a schematic of the solids handling train which presents sludge quantities based on 1988 data. Note that the quantities presented here are all 365 day averages. Because the dewatering and incineration processes actually operate on a five day per week schedule, quantities presented in this schematic could be multiplied by 7/5 to obtain true average day quantities for these processes. Also, the schematic shows average day cake disposal split beween two technologies; sludge incineration and landfilling. Again, these are 365 day averages that do not reflect the true operating schedule. In reality, all sludge cake is incinerated when the incineration system is operational. When the incineration system is shutdown due to maintenance problems or equipment failures, all sludge cake is landfilled until the incineration system is back on-line.

II. UNIT COSTS

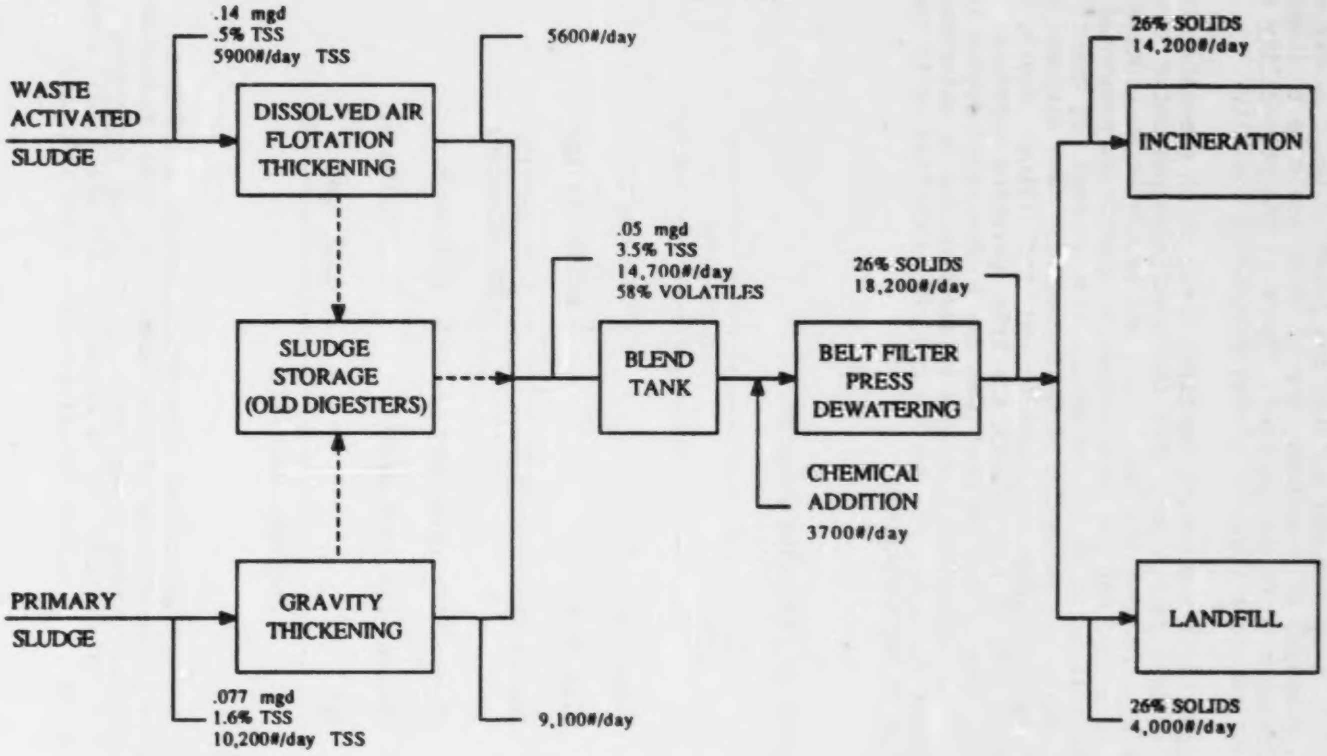
Unit costs are based on 1987-1988 records.

ITEM	UNIT COST
Labor ($/hour)	$ 14.00/hour *
Lime ($/#)	$ 83.90/dry ton
Ferric Chloride ($/#)	$ .1155/wet lb. (30% solution)
Electricity ($/kw-hr)	$ 0.06/kw-hr
Natural Gas ($/therm)	$ 0.6256/100 cf
HCl	$ 0.95/ gal

* includes benefits

III SLUDGE PUMPING

Records of actual metered electrical consumption are not available. Therefore, electrical consumptions will be based upon curves presented in the EPA publication entitled Energy Conservation in Municipal Wastewater Treatment. Based on this source, it is estimated that electrical consumption for sludge pumping at the Cranston facility totals 9,400 kWh/year.


WASTE ACTIVATED SLUDGE
.14 mgd
.5% TSS
5900#/day TSS
DISSOLVED AIR FLOTATION THICKENING
5600#/day
SLUDGE STORAGE (OLD DIGESTERS)
PRIMARY SLUDGE
GRAVITY THICKENING
.077 mgd
1.6% TSS
10,200#/day TSS
9,100#/day
.05 mgd
3.5% TSS
14,700#/day
58% VOLATILES
BLEND TANK
CHEMICAL ADDITION
3700#/day
BELT FILTER PRESS DEWATERING
26% SOLIDS
18,200#/day
INCINERATION
26% SOLIDS
14,200#/day
LANDFILL
26% SOLIDS
4,000#/day

Cranston WPCF Solids Handling Schematic

IV. WASTE ACTIVATED SLUDGE THICKENING

1. GENERAL INFORMATION

Technology: Dissolved Air Flotation Thickeners (DAF)

Date Installed: on-line April 1985

Manufacturer: Envirex

No. of Units: 2

2. DESIGN INFORMATION

Tank Dimensions: effective length 41.25 ft
effective width 14.75 ft

Sidewater Depth: 9 ft

Effective Surface Area: 600 sf/unit
1200 sf total

Solids Loading Rate: 2 lb/sf-hr

3. OPERATING INFORMATION

After plant start-up, the dissolved air flotation thickeners were not used until August of 1988 because of electrical problems. All information presented here will be based upon operating experience during the period from early August 1988 to the end of December 1988.

Average Operating Flow:

FLOW	DAF NO. 1	DAF NO. 2
Recycle Flow	.37 mgd	off-line
Sludge Flow	.12 mgd	
Total Flow	.49 mgd	

Operation Schedule: 365 days

Sludge Feed (#/day): 5900 #/day

% Solids of Sludge Feed: .5% TSS

% Solids of Thickened Sludge: Not Measured

Polymer Use: Not Measured

Odor Control: None

4. COST INFORMATION

A. Capital

Facility Planning Estimate of Capital:	Not Available
Actual Capital Cost (bid + change orders):	

The entire upgrade of the solids handling train was completed under one project (Contract No. 2A). This project was awarded in 1981 and completed in 1985. The Certificate of Payment for Contract 2A is appended to this report. Although the entire upgrade was bid as a lump sum, the total cost has been roughly broken down into process areas (thickening, de- watering, incineration) by identifying major equipment costs and proportioning building costs based on the area occupied by each unit process. Costs for the thickening process (both gravity and DAF thickening) beakdown as follows:

	Original Construction Cost	Updated (ENR=4540) Construction Cost
equipment	$ 2,500,000	$ 3,100,000
structures	$ 2,200,000	$ 2,700,000
Total	$ 4,700,000	$ 5,800,000

This includes the cost for 1 gravity thickener, 1 DAF unit, electrical and mechanical items, and a single level building (approximately 125 ft * 70 ft) to house the thickening equipment.

B. O&M

Item Level	Consumption Cost	Annual
Operations Labor	8 hr/day	$ 40,800
Maintenance Labor	4 hr/week	$ 2,900
Polymer		$ 12,000*
Electricity	400,600 kwh/year	$ 24,000
Replacement Materials		$ 20,000**
Total		$ 99,700

* Spent $6,000 on polymer in the last 6 months of 1988.

** Spent $10,000 on replacement parts and outside contractors during the last 6 months of 1988.

5. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of 60 kWh per dry ton (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities) and a consumption of 40 kWh per square foot of building space for lighting, HVAC, and other general building needs.

Equipment	No. Units	HP
Recycle Pumps	2	30
Air Blowers	2	5
DAF Thickeners	2	4
Polymer Metering Pumps	2	1.5
Thickened Sludge Pumps	2	7.5

Estimated Electrical Consumption (kWh/year):

Equipment	64,600
Building	336,000
TOTAL	400,600

V. GRAVITY THICKENING

Until August of 1988, the gravity thickeners were not used because of plugging problems. All information presented here will be based upon operating experience during the period from early August 1988 to the end of December 1988.

1. GENERAL

No. Units:	1
Type of Sludge:	Primary only

2. DESIGN INFORMATION

Tank Diameter:	38 ft
Tank Depth:	11 ft
Unit Surface Area:	1134 sf
Solids Loading:	20 to 30 lb/sf-day (primary only) 6 to 10 lb/sf-day (primary + waste activated)

3. OPERATING INFORMATION

Percent Solids of Sludge Feed:	about 1.6% TSS
Percent Solids of Product:	not measured
Sludge Feed:	.077 mgd 10,200 #/day
Average Loading Rate (#/sf/day):	9
Average Overflow Rate (gall/sf/day):	124
Maintenance Concerns:	The discharge line plugs with rags frequently.

4. COST

A. Capital

Facility Planning Estimate
of Capital: Not Available

Actual Capital Cost
(bid + change orders):

The entire upgrade of the solids handling train was completed under one project (Contract No. 2A). This project was awarded in 1981 and completed in 1985. Although the entire upgrade was bid as a lump sum, the total cost has been roughly broken down into process areas (thickening, dewatering, incineration) by identifying major equipment costs and proportioning building costs based on the area occupied by each unit process. Costs for the thickening process (both gravity and DAF thickening) breakdown as follows:

	Original Construction Cost	Updated (ENR=4540) Construction Cost
equipment	$ 2,500,000	$ 3,100,000
structures	$ 2,200,000	$ 2,700,000
Total	$ 4,700,000	$ 5,800,000

This includes the cost for 1 gravity thickener, 1 DAF unit, electrical and mechanical items, and a single level building (approximately 125 ft * 70 ft) to house the thickening equipment.

B. O&M

Item	Consumption Level	Annual Cost
Operations Labor	8 hr/day	$ 40,800
Maintenance Labor	2 hr/week	$ 1,500
Electricity	364,500 Kwh/year	$ 21,900
Service Contracts **		$ 2,600
Total		$ 66,800

*Spent $1300 on service contracts in the last 6 months of 1988.

5. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an equipment consumption of .25 kWh per dry ton (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment

Facilities and a consumption of 40 kWh per square foot of building space for lighting, HVAC, and other general building needs (note that the gravity thickener is housed).

Equipment	No. Units	Hr/Day*	HP	KWH/Day
Gravity Thickener	1	24	2	40
Thickened Sludge Pumps	2	24	5	180
Transfer To Chemical Conditioning	3	24	20	1,080
Total				1,300

Estimated Annual Electrical Requirements (kWh/year):

Equipment	500
Building	364,000
TOTAL	364,500

VI. SLUDGE STORAGE TANKS

The original primary plant included three sludge digesters. These digesters are now used as sludge storage tanks. In the current operating mode, sludge is dewatered and incinerated on a 5 day per week schedule. Sludge produced during the weekend is stored in the two sludge storage tanks and fed to the dewatering/incineration processes during the following week. Generally, fresh sludge is processes on Monday and Tuesday and weekend sludge is paced into the system at midweek. This mode of operation has a negative impact on the dewatering/incineration system. Sludge drawn from the storage tank has a much lower volatile content than the fresh sludge that is produced and processed immediately. When weekend sludge from the storage tank is mixed into the dewatering feed, the quality of the sludge changes significantly. This makes it difficult to optimize the chemical conditioning requirements for the dewatering process, therefore the effectiveness of the dewatering operation decreases. Under these conditions, the furnace is very difficult to control because the percent solids and the percent volatiles of the sludge cake feed are fluctuating. To control the furnace under these conditions, the operator will often be forced to use auxiliary fuel to maintain combustion temperatures.

VII. SLUDGE BLEND TANK

1. GENERAL

No. Tanks:	2
Tank Dimensions:	26 ft * 28.5 ft

Tank Depth: 9 ft

Mixing: Mixing provided by propeller mixers. Diffused air is available for mixing, but is not used because this system encourages odor problems.

Mixer Manufacturer: Chemineer

2. OPERATING INFORMATION

Percent Solids of Sludge Feed: Range 1.5% to 5% TSS
Average 3.5% TSS

Percent Volatiles of Feed: 58%

Percent Solids of Product: Same as feed

Chemical Addition: None

Detention Time: about 16 hours

3. COST

A. Capital

Actual Capital Cost (bid + change orders): Included in dewatering costs

B. O&M

Item	Consumption Level	Annual Cost
Operations Labor	2 hr/day	$ 10,200
Maintenance Labor	4 hr/week	$ 3,000
Electricity	30,000 KWH/year	$ 1,800
Chemicals*		$ 4,300
Replacement Materials**		$ 24,000
Total		$ 43,300

* Potassium permanganate used for odor control. This passive system forces off gases to pass through one of four 55 gallon drums filled with potassium permanganate prior to discharge to the atmosphere.

** Have spent $12,000 in the past six months on repairs to the mechanical mixers. Typically, rags get caught in the propellers, creating a torque load on the mixer shaft.

4. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon curves presented in the EPA publication entitled Estimating Sludge Management Costs.

Rated HP of Mixer:	2 @ 20 HP/unit
Typical Hours of Operation:	24 hour/day
Annual Electrical Requirements (kw-hr/year):	30,000

VIII. CHEMICAL CONDITIONING

1. GENERAL INFORMATION

Both a lime and ferric conditioning system and a polymer conditioning system were provided. During design, it was recognized that lime and ferric conditioning would be required in the early years of the plant operation, but it was believed that future improvements in polymer effectiveness may someday make polymer a viable conditioning alternative. Currently, the lime and ferric conditioning system is used exclusively. A general description of each system follows.

In the lime and ferric conditioning system, sludge is pumped to chemical conditioning tanks where it is mechanically mixed with ferric chloride. The sludge then flows by gravity to a flocculation tank where lime is added and the sludge is gently stirred. Conditioned sludge is drawn from the flocculation tank and fed to the filter press. The ferric chloride storage and feed system consists of a ferric storage tank (usable storage capacity of 17,860 gallons), two chemical metering pumps, and a dilution and transport system. The lime storage and feed system consists of a dry lime storage silo, a dry lime feeder, a lime slaker, a lime slurry holding tank, and chemical metering pumps.

The polymer system consists of a concentrated liquid polymer storage tank (usable storage volume 3380 gallons), a package polymer dilution system consisting of a mixing tank and polymer and dilution water pumps, a diluted polymer storage tank, and diluted polymer metering pumps. Concentrated polymer is diluted to a 2 percent solution at the dilution mix tank and is further diluted to a 1 percent solution before adding the polymer to the sludge.

IX. SLUDGE DEWATERING

1. GENERAL INFORMATION

Technology:	Fixed Volume Filter Press Side Bar Type
No. of Units:	3

Date Installed: 1985

Manufacturer: Eimco

See attached figures showing general press component description and filter press system process flow (taken from Universal Engineering Operation and Maintenance Manual for City of Cranston Solids Handling Facilities).

2. DESIGN INFORMATION

Thickened Sludge Quantities (dry lb/day):

Design - 79,500 (design year 2000)
Average - 77,900 (design year 2000)
Mimimum - 58,200 (design year 1980)

Chemical Conditioners (dry lb/day):

Lime
Design Average 15,900
Range 5,800 - 23,900

Ferric
Design Average 4,000
Range 1,800 - 8,000

Total Conditioned Sludge (dry lb/day):

Design - 100,500 (design year 2000)
Average - 97,900 (design year 2000)
Minimum - 59,600 (design year 1980)

No. High Pressure Piston Type Sludge Feed Pumps: 6

% Cake Solids: Design - 35
Range - 25 to 40

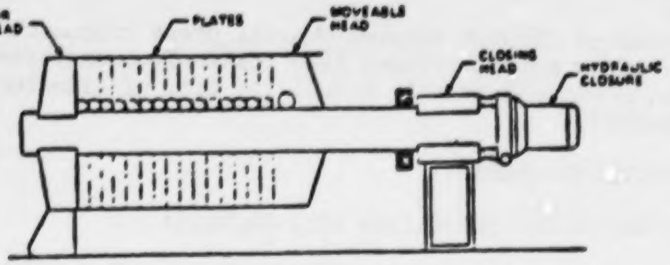
Operating Cycles: 2.5 hour

Operating Pressure: 100 psi

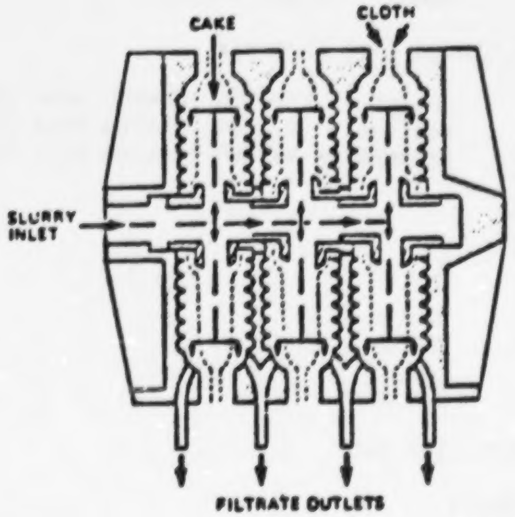
Cake Volume (cf/day):

Design - 4,100
Average - 4,000
Minimum - 2,400

Unit Size: 104 plates (105 chambers)
1.5 m * 2.0 m plates
can be expanded to 115 chambers by adding 10 additional plates


FIXED OR FEED HEAD
PLATES
MOVEABLE HEAD
CLOSING HEAD
HYDRAULIC CLOSURE

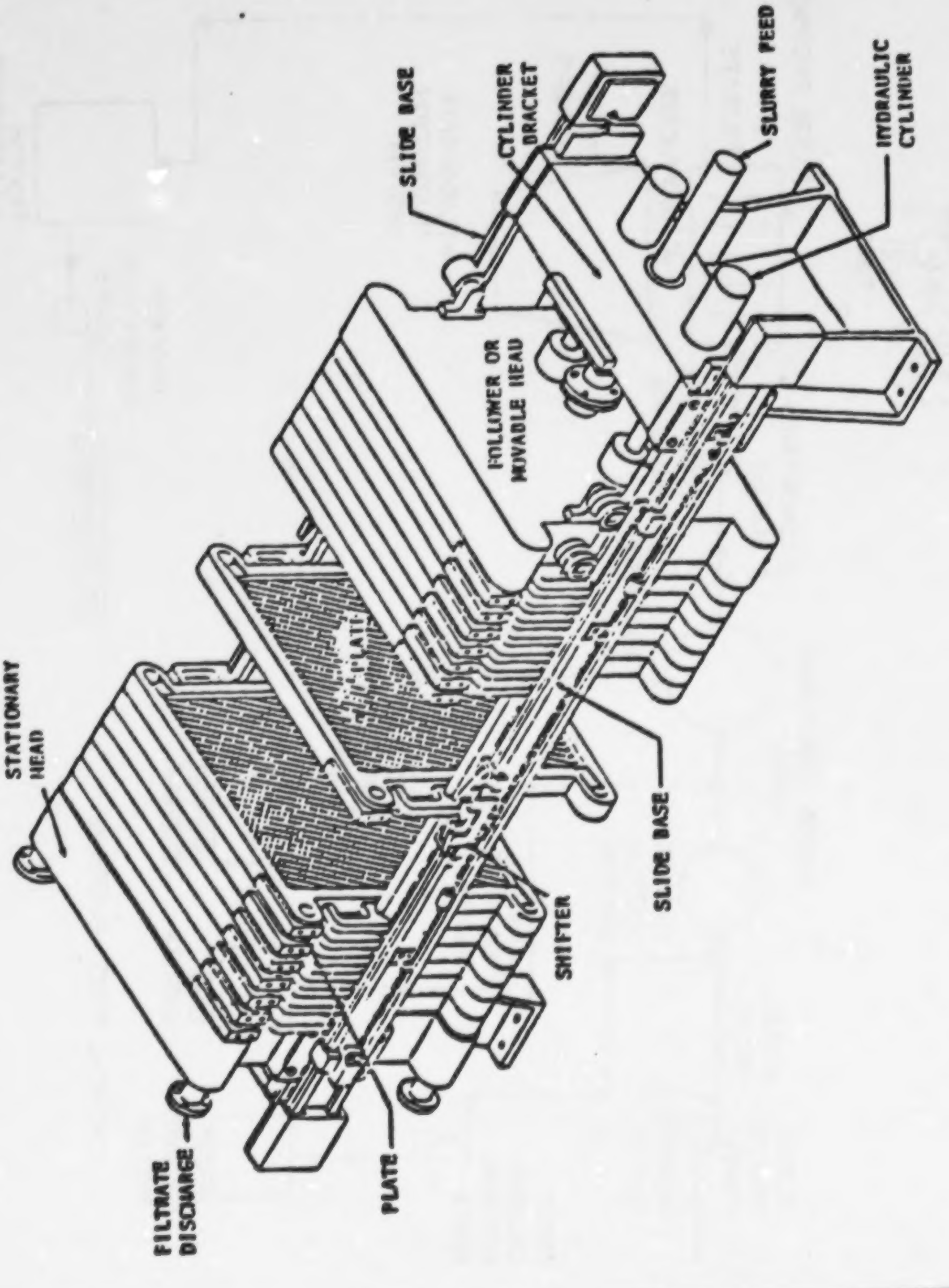
SIDE VIEW


CAKE
CLOTH
SLURRY INLET
FILTRATE OUTLETS

CROSS SECTION ALONG LENGTH OF PRESS

TYPICAL PRESSURE FILTER PRESS INSTALLATION	CITY OF CRANSTON, RHODE ISLAND WATER CONTROL FACILITY

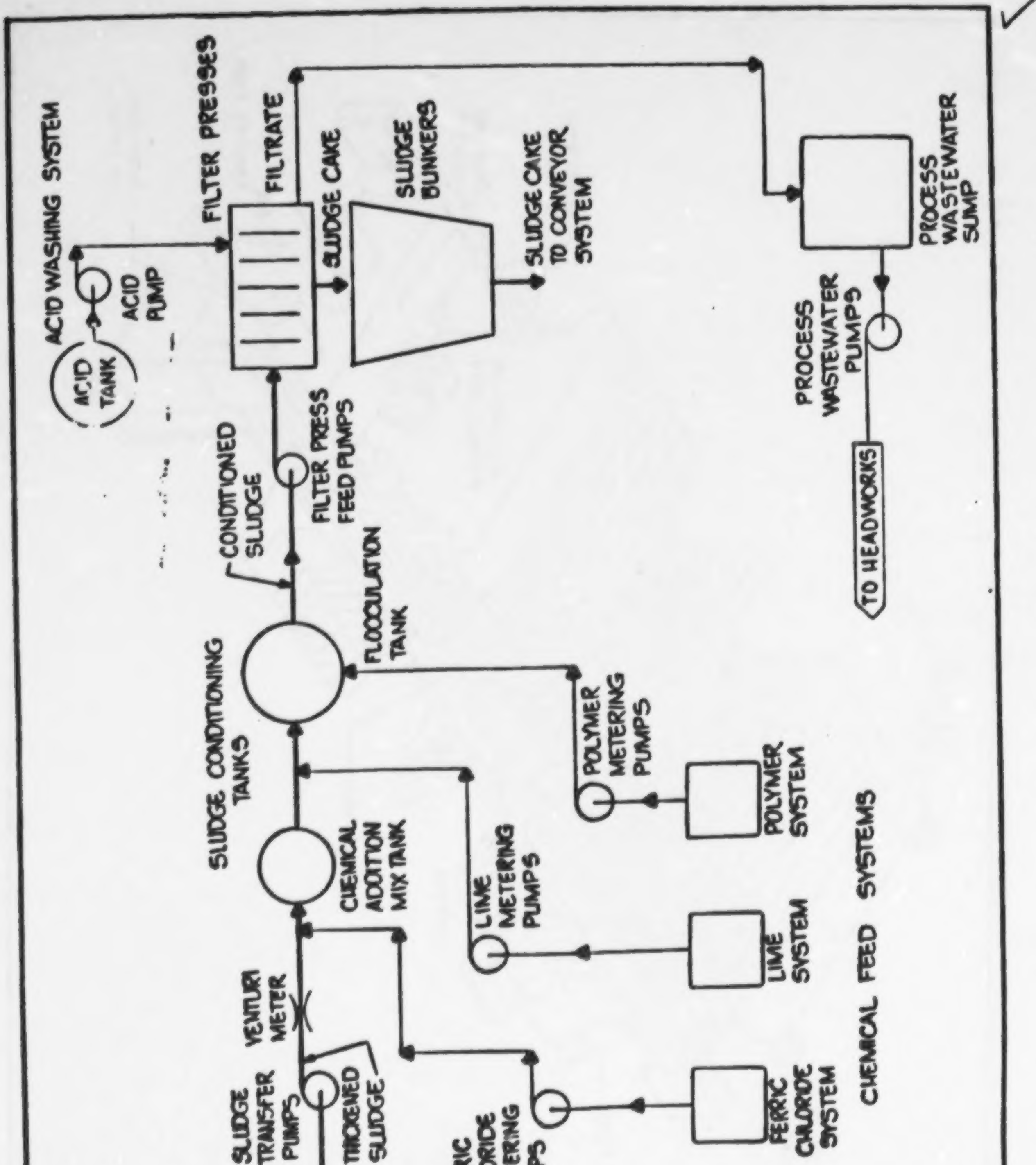
PLATE NO. 4-7


STATIONARY HEAD
FILTRATE DISCHARGE
PLATE
SHIFTER
SLIDE BASE
PLATE
FOLLOWER OR MOVABLE HEAD
SLIDE BASE
CYLINDER BRACKET
SLURRY FEED
HYDRAULIC CYLINDER

GENERAL PRESS
COMPONENT DESCRIPTION

CITY OF CRANSTON, RHODE ISLAND
WATER CONTROL FACILITY

PLATE NO. 4-8

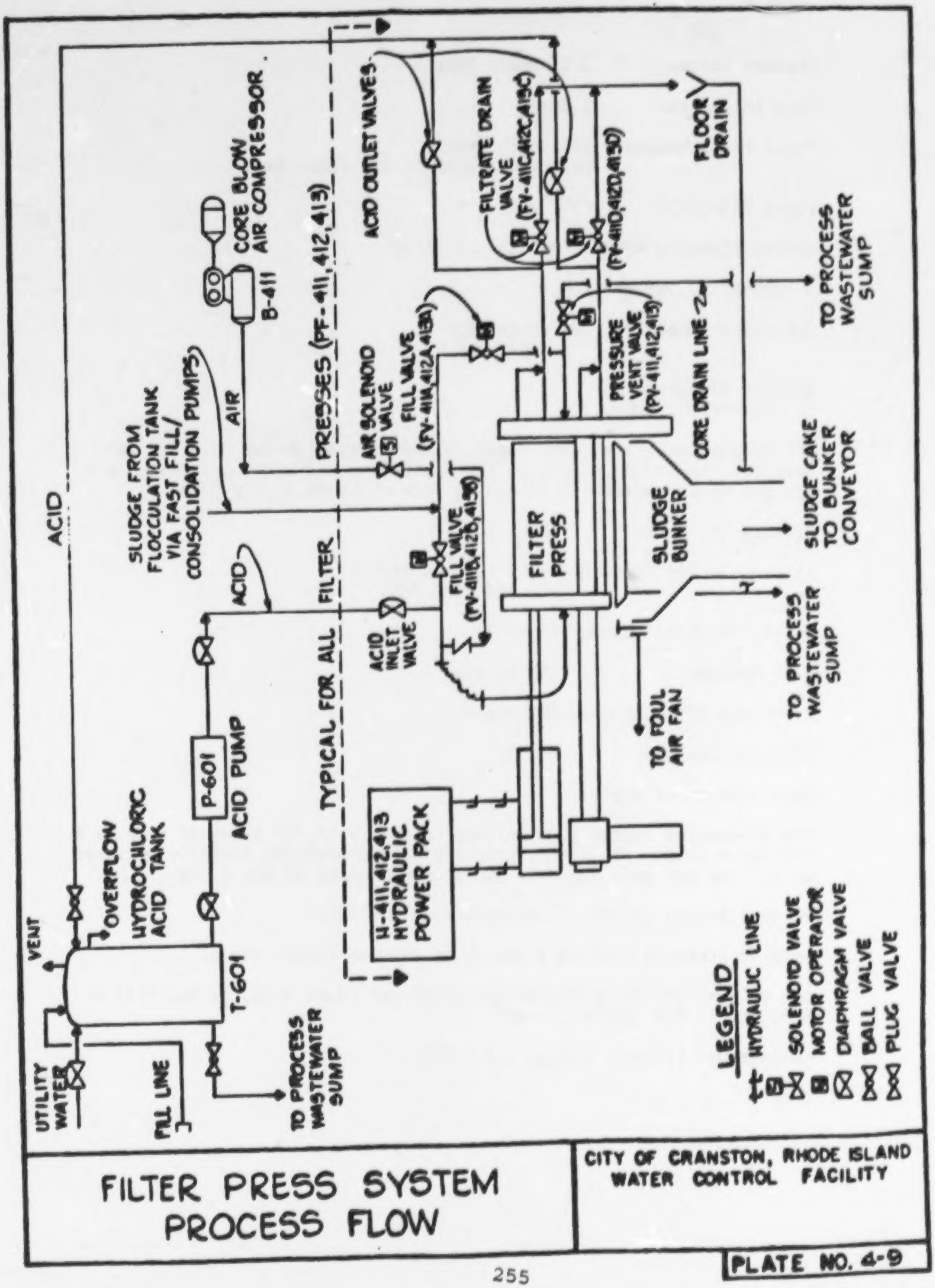


ACID TANK
ACID PUMP
ACID WASHING SYSTEM
FILTER PRESSES
FILTRATE
SLUDGE CAKE
SLUDGE BUNKERS
SLUDGE CAKE TO CONVEYOR SYSTEM
PROCESS WASTEWATER SUMP
PROCESS WASTEWATER PUMPS
TO HEADWORKS
CONDITIONED SLUDGE
FILTER PRESS FEED PUMPS
SLUDGE CONDITIONING TANKS
FLOCCULATION TANK
CHEMICAL ADDITION MIX TANK
SLUDGE TRANSFER PUMPS
THICKENED SLUDGE
VENTURI METER
FERRIC CHLORIDE METERING PUMPS
LIME METERING PUMPS
POLYMER METERING PUMPS
FERRIC CHLORIDE SYSTEM
LIME SYSTEM
POLYMER SYSTEM
CHEMICAL FEED SYSTEMS

SLUDGE DEWATERING SYSTEM PROCESS FLOW

CITY OF CRANSTON, RHODE ISLAND
WATER CONTROL FACILITY

PLATE NO. 4-1


ACID
UTILITY WATER
FILL LINE
VENT
OVERFLOW
HYDROCHLORIC ACID TANK
T-601
TO PROCESS WASTEWATER SUMP
P-601
ACID PUMP
ACID
SLUDGE FROM FLOCCULATION TANK VIA FAST FILL/ CONSOLIDATION PUMPS
AIR
B-411
CORE BLOW AIR COMPRESSOR
TYPICAL FOR ALL FILTER PRESSES (PF-411, 412, 413)
H-411, 412, 413 HYDRAULIC POWER PACK
ACID INLET VALVE
FILL VALVE (FV-411B, 412B, 413B)
AIR SOLENOID VALVE
FILL VALVE (FV-411A, 412A, 413A)
ACID OUTLET VALVES
FILTRATE DRAIN VALVE (FV-411C, 412C, 413C)
(FV-411D, 412D, 413D)
PRESSURE VENT VALVE (FV-411, 412, 413)
FILTER PRESS
SLUDGE BUNKER
CORE DRAIN LINE
FLOOR DRAIN
TO PROCESS WASTEWATER SUMP
SLUDGE CAKE TO BUNKER CONVEYOR
TO PROCESS WASTEWATER SUMP
TO FOUL AIR FAN
LEGEND
HYDRAULIC LINE
SOLENOID VALVE
MOTOR OPERATOR
DIAPHRAGM VALVE
BALL VALVE
PLUG VALVE

FILTER PRESS SYSTEM
PROCESS FLOW

CITY OF CRANSTON, RHODE ISLAND
WATER CONTROL FACILITY

PLATE NO. 4-9

Chamber Volume: 2.17 cubic feet

Cake thickness: 1 inch

Total Press Volume: 228 cubic feet
can be expanded to 250 cubic feet

Plate Material: Cast Iron

Clothe Cleaning Agent: Hydrochloric Acid

3. OPERATING INFORMATION

Operating Schedule: 24 hours/day
5 days/week

Average Sludge Feed to Dewatering (#/day):

The dewatering system feed averages about 14,700 #/day on a 365 day average. In actual practice, the dewatering facility operates on a 5 day per week schedule at a loading rate of about 20,600 #/day.

Primary/WAS Ratio: about 1.6 : 1

Percent Solids of Feed: Range 1.5% to 5% TSS
Average 3.5% TSS

Ferric Chloride Dosage: 6% to 7%

Lime Dosage: 15% to 20%

Frequency of Testing to Optimize Chemical Dosage: Daily

Cake Product (#/day):

The dewatering system produces approximately 18,200 #/day of cake on a 365 day average. In actual practice, the dewatering facility operates on a 5 day per week schedule and produces about 25,500 #/day.

Percent Solids of Cake: Average 26.4 % (1988)

Rate of Pressure Applied & Pacing of Flow to Filter Press:

Can fill at 10,000 to 15,000 gpm at 80 psi (fast fill) or can fill at 5,000 to 10,000 gpm at 100 psi.

Average No. Filters In Use: 1.9 (1988)

Cycle Time :	2.5 to 4 hours in press cavity (no allowance for discharge time)
No. Cycles Per Day:	Avg 7 Max 10 (when operating with a backlog)
Type of Cloth Used:	Polyester
Cloth Washing Frequency:	As Needed (may range from a few days days to three or four months)
Use of Precoat:	None
Solids Capture:	Not Measured
Sidestream Strength:	Not Measured

Operation/Maintenance Problems:

The core blowers which clear liquid sludge from the center ports of the plates do not operate.

The drip trays which collect the filtrate and washwater are badly corroded. As a result, some of the filtrate and washwater leaks through the drip tray and mixes in with the dewatered sludge cake.

4. COST INFORMATION

A. Capital Facilities Plan Estimate of Capital: Not Available

Actual Capital Cost:

The entire upgrade of the solids handling train was completed under one project (Contract No. 2A). This project was awarded in 1981 and completed in 1985. The Certificate of Payment for Contract 2A is appended to this report. Although the entire upgrade was bid as a lump sum, the total cost has been roughly broken down into process areas (thickening, dewatering, incineration) by identifying major equipment costs and porportioning building costs based on the area occupied by each unit process. Costs for the dewatering process beakdown as follows:

	Original Construction Cost	Updated (ENR=4540) Construction Cost
equipment	$ 2,200,000	$ 2,700,000
structures	$ 4,000,000	$ 4,900,000
Total	$ 6,200,000	$ 7,600,000

This includes the cost for the chemical feed systems, the filter press units, and the building space to accomodate these systems.

B. O&M

ITEM	CONSUMPTION LEVEL		ANNUAL COST
Operations Labor	102	hr/week	$ 74,300
Maintenance Labor	24	hr/week	$ 17,500
Lime *			$ 78,400
Ferric Chloride *			$ 103,200
Electricity	1,113,600	kw-hr/year	$ 66,800
Replacement Materials *			$ 30,000
Total			$ 370,200

* Projected annual costs based on the last 6 months of 1988

5. ENERGY CONSUMPTION

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon an eqipment consumption of 30 kWh per dry ton (reference WPCF Manual of Practice No. FD-2 Energy Conservation in the Design of Wastewater Treatment Facilities) and a consumption of 40 kWh per suare foot of building space for lighting, associated with the chemical feed system was made based upon curves presented in the EPA publication Energy Conservation in Municipal Wastewater Treatment.

Equipment	No. Units	HP
Chemical Mix Tank Mixer	1	2
Flocculation Tank Mixer	1	3
Air Compressor	1	30
Fast Fill Pumps	3 total 1.9 avg. operating	50
Consolidation Pumps	3 total 1.9 avg. operating	25
Lime Slakers	2	30
Lime Slurry Pumps	3	7.5
Lime Slurry Metering Pumps	2	7.5
Ferric Metering Pumps	2	1
Total		4955

* In operation 5 days/week

Estimated Annual Electrical Requirements (kw-hr/year):

Equipment	219,600
Building	894,000
TOTAL	1,113,600

X. CAKE STORAGE/EQUALIZATION

Each filter press discharges into a sludge bunker. The purpose of these bunkers is to provide the equalization storage necessary to transform the batch output from the filter press dewatering process into a continuous feed for the incineration system. Under each bunker is a conveyor that transports cake from the three bunkers to a common conveyor which transports the sludge to a sludge feed bin which preceeds each furnace. Cake from this sludge feed bin is withdrawn at a consistent rate to the furnace. This system was designed to be highly automated. A weigh belt feeder was installed to control the output from the sludge feed bin to the furnace. This was provided to insure that a consistent mass of sludge is delivered to the furnaces.

Each sludge bunker was designed with a usable capacity of 900 cubic feet, which equates to almost four filter press loads of 228 cubic feet each. Bunker dimensions are 25.75 feet long by 11.4 feet high with a tapered width of 5 feet at the bunker top and 4 feet at the bunker bottom. Unfortunately, a bridging problem has severly limited the usable capacity of these bunkers. To avoid bridging, the operators store no more than about half a press load at a a time in a hopper. Because one-half press load takes about 2.5 hours to burn and because the cake hoppers are ineffective, the filter presses are used to provide storage for equalization. However, loads from different filter presses (stored in different hoppers) can be blended when fed to the incinerators.

Each sludge feed bin has a usable capacity of 220 cubic feet. Output from these bins was designed to be controlled by the subsequent weigh belt feeder. Probes were installed within the bin to monitor the depth of cake within the bin. These probes would automatically control the speed of the cake conveyor which transfers cake from the sludge bunkers to the feed bin. If the feed bin became too full, the probes would automatically turndown the cake conveying system. There have been problems with this automated feed system. The weigh belt system would maintain a steady feed if the quality of the cake was consistent. However, variations in the percent solids of the sludge cake and in the quality of the cake (digested sludge versus raw sludge) have resulted in variations in the furnace feedrate. Problems with the probes in the feed bins have also limited the effectiveness of the automated conveyor system. At other times, the probes do work properly, but the conveying system has difficulty turning down enough to match the probe's signal. Problems with the conveying system have at times resulted in the shutdown of the entire dewatering/incineration system.

In addition, the drip trays which separate the filter press discharge area from the sludge storage bunker have experienced a severe corrosion problem. As a result, filtrate and cloth washwater often leak through the drip tray and mix with the bunker sludge, reducing the effectiveness of the dewatering process.

XI. GRIT, SCREENINGS, AND SCUM DISPOSAL

GRIT DISPOSAL: Landfilled

SCREENINGS DISPOSAL: Landfilled

SCUM AND GREASE DISPOSAL:

A scum concentrator is used to concentrate and homogenize the grease and scum. The unit is manufactured by the Walker Process Corporation and is called a Grease Preparation System. The system is essentially a 2-stage gravity separation device. This grease and scum mixture is then fed to the incinerator at 1 gpm.

XII. INCINERATION

1. GENERAL INFORMATION

Technology:	Multiple Hearth Incineration
No. Units:	2
Manufacturer:	1 by Nichols 1 by Crouse

Date Installed:

One unit (Nichols) is about 40 years old, but was rarely used until 1986. The second unit (Crouse) was placedon-line in fall of 1986.

Operational Status:

When the upgraded incineration system went on-line in 1986, the Crouse unit experienced several start-up problems that severly limited its operation. The EPA limited operation of the Crouse unit to about 80% of its full capacity because of emmissions problems during start-up. A lack of sludge also made it difficult to operate the bigger Crouse furnace efficiently. As a result, the Nichols furnace was operated full time from start-up in spring of 1986 to the fall of 1987. At this time, several problems forced the staff to take the Nichols furnace out of operation. Among these were problems with the center shaft, refractory damage, and damage to rabble teeth on hearth no. 1 and hearth no. 2. Since this time, the Crouse furnace has been used exclusively. Each furnace has a separate scrubbing and heat recovery system.

No. of Hearths Per Unit: Crouse - 6 hearth
Nichols - 6 hearth

Each furnace also has an external afterburner chamber

Diameter: Crouse - 18 ft 9 in; hearth area 1657 sf
Nichols - 14 ft 3 in; hearth area 957 sf

2. OPERATING PARAMETERS

Operating Schedule: 5 days per week
24 hours/day

Design Peak Loading Rate:

The Nichols furnace has a rated capacity of 4,600 wet pounds per hour of dewatered cake with 35% solids. The Crouse furnace has a rated capacity of 8,890 wet pounds per hour of dewatered cake with 28% solids.

Average Loading Rate:

The sludge cake feed to the incineration system averages 14,200 #/day for a 365 day average. However, the furnace normally operates on a 5 day per week schedule at a loading rate of approximately 19,900 #/day (3200 wet #/hour). It has been found that the optimum feed rate for the Crouse furnace is 5,200 wet pounds per hourbut, because of a lack of sludge, the furnace is almost always operated at less than optimum feed rates.

No. Units typically in Operation: 1 unit in operation unit in stand-by mode

Average Hearth Loading Rate: 2 #/sf-hour (Crouse furnace)

Rotational Speed of Rabble Arms: minimum 1 rpm

Percent Excess Air:

Cannot be measured accurately because of air leaking into the top hearth of the furnace.

Average Volume of Shaft Cooling Air Returned As Consumption Air: Varies

The furnaces were designed for operation in the pyrolysis (starved air) mode, but have only operated in this manner during start-up. To operate in the convential incineration mode, air must be introduced into the furnace eithier by recycling the center shaft cooling air or by opening access doors on the hearths. Typically, the access doors are kept closed, therefore all combustion air must first pass through the center shaft. Recycled center shaft cooling air can be delivered to any hearth or combination of hearths. The operator must adjust the recycle rate of the cooling air to match the excess air requirements within the furnace. Because the flue gas oxygen analyzer does not produce usable data, the operator must visually observe the stack emissions as a guide to the current excess air requirements within the furnace.

Typical Temperature Profile of Incineration System (degrees F):

Hearth	Temperature (degrees F)
Hearth 1	875
Hearth 2	1220
Hearth 3	1380
Hearth 4	1475
Hearth 5	890
Hearth 6	490
Cooling Shaft Air	140
Afterburner Chamber	730
Subcooler Temperature	60

Although auxiliary fuel is never used in the afterburner, the gas temperature usually rises slightly as it passes through this chamber, as the addition of air completes the combustion of remaining volatiles.

3. COST INFORMATION

A. Capital

Facilities Plan Estimate of Capital: Not Available

Actual Capital Cost (bid + change orders):

The entire upgrade of the solids handling train was completed under one project (Contract No. 2A). This project was awarded in 1981 and completed in 1985. The Certificate of Payment for Contract 2A is appended to this report. Although the entire upgrade was bid as a lump sum, the total cost has been roughly broken down into process areas (thickening, dewatering, incineration) by identifying major equipment costs and proportioning building costs based are occupied by each unit process. The incineration costs breakdown as follows:

	Original Construction Cost	Updated (ENR=4542) Construction Cost
equipment	$ 8,400,000	$ 10,300,000
structures	$ 2,400,000	$ 2,900,000
Total	$12,400,000	$ 13,200,000

This includes the cost to install the new furnace, the cake conveying system, and the air pollution control and heat recovery systems, the cost to refurbish an existing furnace, and the cost for building space apportioned to the incineration system.

B. O&M

ITEM	CONSUMPTION LEVEL		ANNUAL COST
Operations Labor	102	hr/week	$ 74,300
Maintenance Labor	24	hr/week	$ 17,500
Fuel Use *	35,000,000	CF/YEAR	$ 219,500
Chemicals		None	
Electricity	1,864,400	kw-hr/year	$ 111,800
Equipment Service Contracts **			$ 127,800
Replacement Materials			$ 11,000
Totals			$ 561,900

*The cost for natural gas is based on the period from July 1, 1987 to July 1, 1988. Because of the metering system at the Cranston facility, it is impossible to distinguish between gas consumed within the furnace and gas used for building heat. However, during the 1987-1988 heating season, the waste heat recovery system was in full operation and provided essentially all of the required building heat. Therefore, all natural gas consumed during this period was used in the furnaces.

**Major repair items that were contracted out in 1987 included:

- replace oxygen analyzer	$12,500
- replace rabble arms	$24,600
- repair transfer conveyor	$38,200
- repair transfer conveyor	$27,600
- instrumentation repair	$24,900

Operation Guidelines:

The Crouse furnace is designed to be very automated. Under normal operation, the distribution of combustion air to the hearths is set by the position of the dampers and remains constant. If all instrumentation equipment was fully operational, the combustion air feedrate would be controlled automatically by the percent oxygen in the exhaust gas. The burners would be controlled by temperature probes in the incinerator. The automatic controls would maintain a constant sludge feed rate by adjusting the conveyor speeds. The operator would set the sludge feed rate and desired hearth temperatures and essentially allow the furnace to operate itself.

However, the plant staff has experienced several problems with this automated control system. The flue gas oxygen analyzer does not produce useful information. The gate controlling the drop chute at the top of hearth no. 1 does not operate properly. The gate allows air to enter the top hearth through the sludge feed opening. This additional air introduced at the top hearth results in misleading readings by the oxygen analyzer. The oxygen analyzer will record that there is plenty of excess oxygen in the flue gas stream even when there is a shortage of oxygen within the furnace. As a result, the operators must ignore the oxygen analyzer data and adjust the excess air level based on visual inspection. The operators observe the stack emissions regularly and if the stack begins to smoke, the excess air level is increased. The temperature probes within the furnace do operate properly and the burners are generally controlled automatically by the probes, although the operators do manually override this system at times.

The automated conveyor system does not deliver a consistent feed to the furnace. This is due in part to problems with the probes used to monitor cake levels within the sludge bunkers and feed bins and in part due to the variability in the sludge cake. Even when working properly, the weigh belt system can only deliver a consistent sludge feed to the furnace if the sludge produced by the dewatering process is fairly consistent. In the current five day per week operation mode, sludge produced over the weekend is stored in sludge storage tanks (formerly used as digesters). When the incineration system is started up on Monday morning, fresh sludge is fed to the furnace to establish good burn conditions. It is not until midweek that the staff begins to feed sludge that has been stored since the weekend to the dewatering/incineration system. Because of its age, this sludge has a much lower volatile content and does not dewater as well as the fresh sludge. This variability in the quality of the sludge feed makes it impossible for the dewatering process and the subsequent conveying system to deliver a consistent sludge feed to the furnace. As a result, the furnace is very difficult to control.

Operations/Maintenance Concerns:

- Much of the incineration equipment is very inaccessible, making it very difficult to perform regular maintenance or necessary repairs. In some instances, equipment was squeezed into a location without proper clearance, making it impossible to work on the equipment. In other instances, equipment was installed at a high elevation without ladders or catwalks to provide access.

- The plant staff has had a very difficult time getting useful information from the instrumentation. Much of the instrumentation equipment, such as the flue gas oxygen analyzer and the cake weigh belts, does not provide accurate information because of other failures within the incineration system. As a result, the operators often must operate the furnace blindly. The only way for the operator to gauge the effectiveness of the combustion process is to observe the quality of the stack emissions. This is a very ineffective way to operate the furnace, as the operator is not able to identify changing conditions within the furnace until visible stack emissions resulting from incomplete combustion develop.

- A lack of process understanding among the operators has resulted in several operations problems. The incineration process is a relatively complex process. Several variables can be adjusted to achieve a desired result. Operators need some experience with the system to learn how the furnace will react under different circumstances. This learning process has been hampered by the problems with the system instrumentation and the manpower shortage at the plant.

- The facility is understaffed, making it very difficult to implement a preventive maintenance program.

- Typical sludge cake requies auxiliary fuel consumption because of the relatively low solids and volatiles content of the sludge (26% solids and 47% volatiles). This problem is made worse by the frequent furnace shutdowns resulting from a lack of sludge and equipment failures. The current level of sludge production only allows for a 5 day per week operation schedule and, even with this reduced schedule, the furnaces must be operated well below their optimum feed rate. Each Friday, the lead furnace is slowly brought down from combustion temperature to a stand-by temperature of 900°F. On Monday morning, the furnace is slowly returned to combustion temperature. In addition to these scheduled shutdowns, frequent equipment failures have resulted in several unscheduled shutdown periods. When there is an equipment failure, the operators and maintenance staff usually cannot be sure how long the furnace will be out of service. If it appears that it will only be for a short period, the combustion hearth temperature is maintained at 1200°F during the shutdown. These shutdowns, both scheduled and unscheduled, result in a tremendous amount of auxiliary fuel use.

4. ENERGY CONSUMPTION

Equipment	Rated HP
Center Shaft Drive	15
Center Shaft Cooling Air Fan	25
Clinker Grinder	3
Clinker Ash Screw	1.5
ID Fan	100
Ash Bucket Elevator	1.5
Ash Screw	2
Ash Conditioner Screw	3
Belt Conveyor	1.5
Weigh Belt Conveyor	1
Transfer Sludge Conveyor	7.5
Sludge Combustion Air Fan	25
Sludge Feed Bin Conveyor	5
Ash Rotary Air Lock	1
Ash Cooler	2
Burner Air Fan	40
Sludge Shredder	5
Instrument Air Compressor	7.5
Total	246.5

Records of actual metered electrical consumption are not available. Therefore, electrical consumption is estimated based upon Figure 3-113 of the EPA publication entitled Energy Conservation in Municiapl Wastewater Treatment and electrical consumption for general building needs such as lighting and HVAC is estimated based upon a value of 40 kWh per square foot of building space.

Estimated Total Annual Electrical Requirements (kw-hr/year):

Equipment	900,000
Building	964,000
TOTAL	1,864,000

Annual Auxiliary Fuel Use:

During the period from July 1, 1987 to July 1, 1988, 35,000,000 cubic feet of natural gas were consumed at the Cranston facility. During this heating season, the waste heat recovery system was operable and was able to meet virtually all of the facility's building heat needs. Therefore, all of the natural gas consumed during this period was utilized by the furnaces. This natural gas consumption level equates to about 13,540 cubic feet per dry ton of sludge, or the equivelent of about 98 gallons of fuel oil per dry ton. It is impossible to break this fuel use down into fuel consumed during start-up and cool-down periods and fuel used during steady state operation, but it is safe to conclude that this very high fuel consumption is a direct result of the five day operation schedule and the frequent unscheduled maintenance shutdowns.

5. ENERGY RECOVERY

The exhaust gases from the furnace pass through a waste heat exchanger. The heat exchanger transfers heat at a hot gas/heating oil interface and then at a heating oil/water interface. The final product is hot water which can be used for space heating throughout the plant. The temperature of the gas at the heat exchanger outlet is about 400 to 500 F. The waste heat recovery system was put into operation in the Fall of 1987. The system worked successfully in the 1987-1988 heating season, but in June 1988 had to be taken off-line due to a severe corrosion problem. The corrosion occurred on the gas stream side of the exchanger and was so severe that all the heating oil leaked from the exchanger. The incineration system is now operating without heat recovery.

VIII. AIR EMMISSIONS CONTROL

1. GENERAL INFORMATION

Technology:

Top hearth gases pass through an external combustion chamber where, although no auxiliary fuel is used, the gas temperature rises slightly as the addition of air completes the combustion of remaining volatiles. Gases then pass through a waste heat exchanger, a water spray precooler, a variable throat venturi scrubber, and an impingement tray scrubber/subcooler prior to discharge to the atmosphere. The scrubber system is designed for a pressure drop of 25 inches W.C.

Scrubber Manufacturer: Caston

Date of Last Emmissions Test:

Stack height: 50 feet

Building Height: 35 feet

Scrubber Water Treatment: Passavant Lamellar System

Scrubber Water Characteristics (Q,TSS,BOD):

Lamellar Influent	115 mg/l
Lamellar Effluent	15 mg/l
Flow	225 to 300 gpm

XIV. ASH DISPOSAL

1. GENERAL INFORMATION

Technology:

Dry ash system consisting of a bucket elevator, a screw conveyor, and a storage silo before discharge to a truck for hauling. Location of Landfill (on-site/off-site): Johnston, RI Total Annual Volume of Ash Landfilled (cy/year): 1550 cy/year (assumed .6 cy ash/dry ton of cake incinerated).

2. COST INFORMATION

A. Capital

Cost of Truck(s): In 1981, purchased 2 trucks at $80,000/unit and 1 payloader at $80,000.

Cost of Landfill (if owned by district): N/A

Tipping Fee at Landfill (if commercially operated): $29/ton

B. O&M

ITEM	CONSUMPTION LEVEL		ANNUAL COST
Operations Labor	8	hr/day	$ 40,800
Maintenance Labor	0	hr/day	$ 0
Tipping Fees			$ 20,000
Replacement Materials			$ 10,000
Total			$ 70,800

XV. MANPOWER ALLOCATION

The current operations and maintenance staff is budgeted for 10 operators dedicated to the solids train and 4 maintenance personnel for the entire facility. The 10 operators each work a 40 hour week covering the Monday thru Friday round-the-clock operation. The maintenance personnel work a conventional 40 hour week of Monday thru Friday, 8 hours per day. The plant staff has had a problem filling some vacant positions, so the staff is often operating with even less personnel than is allowed for in the budget. When a complete staff is available, available labor hours are typically split between unit processes as follows:

	Operations Staff (10 operators)	Maintenance Staff (4 personnel)
DAF Thickening	56 hours/week	4 hours/week
Gravity Thickening	56 hours/week	2 hours/week
Sludge Blending	28 hours/week	4 hours/week
Sludge Dewatering	102 hours/week	24 hours/week
Incineration	102 hours/week	24 hours/week
Ash Disposal	56 hours/week	0 hours/week
Subtotal	400 hours/week	58 hours/week
Liquid Train	0 hours/week	102 hours/week
Total	400 hours/week	160 hours/week

The plant management realizes that the treatment facility is understaffed and alternatives such as contract operations are being explored to correct the situation. Outside contractors are used extensively to assist the plant staff with mechanical, electrical, and process control problems.

COST SUMMARY TABLES

The following tables attempt to (1) estimate a reasonable construction cost for the existing Cranston WPCF solids handling facilities in 1988 dollars; (2) convert the construction cost to an annual amortized cost; and (3) present a total annual cost (capital plus O&M) for each unit process. Capital costs have been estimated by updating the original construction costs to 1988 dollars using the Engineering News record (ENR) cost index. Operation and maintenance costs have been summarized based on the tables presented earlier in this report.

It should be emphasized that construction costs for such a facility are very difficult to estimate and, even if estimated accurately, are very difficult to use in comparison with other facilities. In reviewing these costs, the reader should consider the following comments:

- Building prices for two similiar facilities can be very different depending on such site-specific factors such as depth of ledge, local materials costs, site constraints, construction market conditions, or other construction considerations.

CRANSTON WPCF
CONSTRUCTION COSTS

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4540)	AMORTIZED CAPITAL COST
Slusge Thickening		
-structures	$2,700,000	$226,400
-equipment	$3,100,000	$315,700
-total	$5,800,000	$542,100
Sludge Dewatering		
-structures	$4,900,000	$410,900
-equipment	$2,700,000	$275,000
-total	$7,600,000	$685,900
Sludge Incineration		
-structures	$2,900,000	$243,200
-equipment	$10,300,000	$1,049,100
-total	$13,200,000	$1,292,300

CRANSTON WPCF
ANNUAL COSTS FOR SOLIDS
HANDLING PROCESSES

PROCESS	CAPITAL	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS & SUPPLIES	CONTRACTED SERVICES	TOTAL COST	% TOTAL ANNUAL COST	CAPITAL COST $/DRY TON	O&M COST $/DRY TON	TOTAL COST $/DRY TON
Sludge Pumping	--	$0	$600	$0	$0	$0	$0	$600	0.02%	$0	$0	$0
W.A.S. Thickening	$542,100	$43,700	$24,000	$0	$12,000	$20,000	$0	$641,800	17.19%	$50	$30	$80
Primary Sludge Thickening	*	$42,300	$21,900	$0	$0	$0	$2,600	$66,800	1.79%	$0	$20	$20
Sludge Blending Tanks	**	$13,200	$1,800	$0	$4,300	$24,000	$0	$43,300	1.16%	$0	$13	$13
Sludge Dewatering	$685,900	$91,800	$66,800	$0	$181,600	$30,000	$0	$1,056,100	28.29%	$63	$111	$174
Sludge Incineration	$1,292,300	$91,800	$111,800	$219,500	$0	$11,000	$127,800	$1,854,200	49.66%	$118	$169	$287
Ash Disposal	***	$40,000	$0	$0	$0	$10,000	$20,000	$70,000	1.90%	$0	$21	$21
TOTAL	$2,520,300	$323,600	$226,900	$219,500	$197,900	$95,000	$150,400	$3,733,600	100.00%	$230	$365	$595

Note: All costs are based on 1988 consumption records.
All capital costs based on September 1988 cost index.

Capital costs have been converted to a $/dry ton basis
based on the system capacity of 30 dry tpd.

O&M costs have been converted to a $/dry ton basis
based on 1988 sludge production of 9.1 dry tpd of dewatered cake.

* Included in primary sludge thickening capital costs

** Included in sludge dewatering capital costs

*** Included in the incineration system costs

- The amount of reserve capacity built into a facility can significantly affect construction costs. The amount of reserve capacity allowed for during design can depend on several factors such as site-specific constraints, plans for future expansion or growth, and the design consultant's philosophy concerning system redundancy.

In converting the estimated construction cost to an annual cost, it was assumed that all structures would have a useful life of 40 years and all equipment would have a useful life of 20 years. A discount rate of 8 percent was assumed to determine an appropriate capital recovery factor.

XVII. SUMMARY OF ENERGY REQUIREMENTS

The following table summarizes energy consumption requirements for each unit process. To allow a true comparison of energy efficiency with other facilities, each form of energy consumption (electricity, fuel oil, natural gas, steam) has been converted to a common unit (BTUs). The energy consumption of each unit process has been determined based on tables presented earlier in this report. The net energy consumption for each unit process and for the system as a whole has been determined and expressed on a per ton basis. Factors used to convert each energy form to a BTU basis appear at the bottom of the table. These factors reflect the BTUs of energy required to produce a kw-hour of electricity and a pound of steam. These conversion factors account for inefficiencies in the production of electricity and steam.

XVIII. LESSONS LEARNED

The design and operating experience at Cranston WPCF offers several insights into fuel-efficient sludge incineration.

Operators at the Cranston facility emphasize the importance of consistency in the operation of the incinerator. Any changes to the system should be made gradually. A consistent sludge feed is essential to fuel-efficient operation.

Operation of a multiple hearth furnace on a five day per week schedule is very costly because of the fuel required to maintain stand-by temperatures over the week-end. Unscheduled shutdowns due to maintenance problems also significantly increases auxiliary fuel use.

Sludge hoppers should be designed to avoid bridging. A tremendous amount of sludge storage at Cranston is being lost because of bridging.

CRANSTON WPCF
ENERGY REQUIREMENTS FOR SOLIDS HANDLING PROCESSES

	ENERGY CONSUMPTION							
PROCESS	ELECTRICITY * (KW-HR/YEAR)			FUEL OIL (GAL/YEAR)	NATURAL GAS (CF/YEAR)	TOTAL BTUs CONSUMED	% TOTAL BTU CONSUMPTION	BTU/DRY TON **
	Building	Equip	Total					
Sludge Pumping	--	9.400	9,400	0	0	94,000,000	0.13%	28.300
W.A.S. Thickening	336,000	64,600	400,600	0	0	4,006,000,000	5.50%	1,206.082
Primary Sludge Thickening	364,000	500	364.500	0	0	3,645,000,000	5.01%	1,097,396
Sludge Blending	--	30.000	30,000	0	0	300,000,000	0.41%	90.321
Sludge Dewatering	894,000	219,600	1,113,600	0	0	11,136,000,000	15.29%	3,352,702
Sludge Incineration	964.000	900,000	1,864.000	0	35,000,000	53,640,000,000	73.66%	16,149.330
TOTAL	2,558,000	1,224,100	3,782,100	0	35,000,000	72,821,000,000	100.00%	21,924,131

NOTE: Electricity 10,000 BTU/kw-hr
Fuel Oil 138,000 BTU/gal
Natural Gas 1000 BTU/cf

** Based on 1988 sludge production of 9.1 dry tpd of dewatered sludge cake.

* All elctrical consumption values are based upon connected horsepower. Actual metered values are not available.

APPENDIX E
SUMMARY OF OPERATION AND MAINTENANCE COSTS AT CURRENT LOADING CONDITION

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TABLE 8-1
METRO WPCP
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT CURRENT LOADING CONDITION
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS & SUPPLIES	CONTRACTED SERVICES	TOTAL O&M COST	COST CREDIT	NET O&M COST	% TOTAL NET COST	NET $/DRY TON
Sludge Pumping[1]	$ 0	$ 176,500	$ 0	$ 0	$ 0	$ 0	$ 176,500	$ 0	$ 176,500	1.35%	$ 2.72
W.A.S. Thickening	513,000	374,300	0	0	240,400	3,500	1,131,200	0	1,131,200	8.67%	17.46
Primary Sludge Thickening	310,700	38,600	0	15,000	45,300	11,000	420,600	0	420,600	3.23%	6.50
Sludge Storage Tanks	539,300	120,900	0	20,500	49,500	700	746,900	0	746,900	5.73%	11.53
Thermal Conditioning	1,234,600	344,000	0	22,700	239,300	17,300	1,857,900	0	1,847,900	14.25%	28.52
Sludge Dewatering	1,373,700	207,000	0	780,600	65,500	4,800	2,451,600	0	2,451,600	18.80%	37.84
Sludge Incineration[2]	3,233,000	826,300	273,400	0	558,000	104,400	4,995,100	0	4,995,100	38.23%	77.10
Boiler System	892,400	272,100	944,300	55,500	131,200	9,600	2,325,100	1,543,200	781,900	6.00%	12.07
RBC System	197,100	123,300	0	69,000	88,100	11,800	489,300	0	489,300	3.75%	7.55
TOTAL	$8,293,800	$2,481,000	$1,217,700	$971,300	$1,457,300	$163,100	$14,584,200	$1,543,200	$13,041,000	100.00%	$201.27

1 dry ton = 0.9072 dry tonnes

[1] This line item includes pumping from the primary and secondary clarifiers to the sludge thickening process. All subsequent sludge pumping is included in the appropriate unit process line item.

[2] Includes ash disposal costs.

NOTE: All costs adjusted based on the unit costs developed in Section 6.

All costs based on average sludge cake production of 177.5 dry tons per day.

TABLE E-2
UPPER BLACKSTONE WPCF
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT CURRENT LOADING CONDITION
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS	TOTAL O&M COST	% TOTAL O&M COST	O&M COST $/DRY TON[1]
Sludge Pumping	$ 39,000	$ 800	$ 0	$ 0	$ 1,000	$ 40,800	3.55%	$ 3.71
W.A.S. Thickening	18,200	51,800	0	0	3,300	73,300	6.39%	6.67
Holding Tanks	3,000	100	0	0	0	3,100	0.27%	0.29
Blending/Dewatering	283,300	57,400	0	79,800	26,000	446,400	38.89%	40.64
Sludge Incineration	295,500	150,400	51,100	0	53,300	550,300	47.94%	50.09
Ash Disposal	28,000	0	0	0	5,900	33,900	2.95%	3.08
TOTAL	$667,000	$260,500	$51,100	$79,800	$89,500	$1,147,800	100.00%	$104.47

1 dry ton = 0.9072 dry tonnes

NOTE: All costs adjusted based on the unit costs developed in Section 4.

All costs based on FY88 average sludge cake production of 30.1 dry tons per day.

TABLE B-3

DUFFIN CREEK WPCP
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT CURRENT LOADING CONDITION
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS	PURCHASED SERVICES	TOTAL O&M COST	COST CREDIT	NET O&M COST	% TOTAL NET COST	NET $/DRY TON
Sludge Pumping	$ 0	$ 1,000	$ 0	$ 0	$ 0	$ 0	$ 1,000	$ 0	$ 1,000	0.04%	$ 0.09
Sludge Digestion	54,100	64,400	0	0	7,400	14,800	140,700	0	140,700	6.06	14.33
Sludge Dewatering	388,800	52,500	0	208,200	117,900	32,800	800,200	0	800,200	34.47	81.50
Sludge Incineration	481,800	101,400	270,000	24,600	420,800	65,600	1,364,200	135,900	1,228,300	52.91	125.12
Ash Disposal	16,500	0	0	0	26,600	108,200	151,300	0	151,300	6.52	15.39
TOTAL	$941,200	$219,300	$270,000	$232,800	$572,700	$221,400	$2,457,400	$135,900	$2,321,500	100.00%	$236.43

1 dry ton = 0.9072 dry tonnes

NOTE: All costs based on 1987 consumption records and 1987 sludge production (9832 tons/year of dewatered cake).
All costs presented in U.S. dollars and based on September 1988 cost index.
All costs adjusted based on unit costs developed in Section 4.

TABLE 8-4

CRANSTON WPCF

O&M COSTS FOR SOLIDS HANDLING PROCESSES

FOR CURRENT LOADING CONDITION

($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS & SUPPLIES	CONTRACTED SERVICES	TOTAL O&M COST	% TOTAL O&M COST	O&M COST $/DRY TON
Sludge Processing	$ 0	$ 500	$ 0	$ 0	$ 0	$ 0	$ 500	0.05%	$ 0.15
W.A.S. Thickening	46,900	17,500	0	12,000	20,000	0	96,400	8.76%	29.02
Primary Sludge Thickening	45,400	16,400	0	0	0	2,600	64,400	5.85%	19.39
Sludge Blending Tanks	14,100	1,400	0	4,300	24,000	0	43,800	3.98%	13.19
Sludge Dewatering	98,300	50,100	0	181,600	30,000	0	360,000	32.72%	108.38
Sludge Incineration	142,100	83,900	140,000	0	21,000	147,800	534,800	48.62	161.01
TOTAL	$346,800	$169,800	$140,000	$197,900	$95,000	$150,400	$1,099,900	100.00%	$331.14

1 dry ton = 0.9072 dry tonnes

*Includes ash disposal costs.

NOTE: All costs adjusted based on unit costs developed in Section 4.

All costs based on 1988 average dewatered sludge cake production of 9.1 dry tpd.

TABLE 8-5
COMPARISON OF ANNUAL SOLIDS HANDLING COSTS
FOR SLUDGE THICKENING
AT CURRENT LOADING CONDITION
($/YEAR)

	METRO (1)			BLACKSTONE (2)			CRANSTON (3)		
	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT
CAPITAL	$2,276,000	$35.13	56.84%	$287,000	$26.10	70.99%	$550,600	$165.77	77.34%
LABOR	823,700	12.71	20.57%	60,200	5.48	14.89%	92,300	27.79	12.97%
ELECTRICITY	589,400	9.10	14.72%	52,700	4.80	13.04%	34,400	10.36	4.83%
FUEL	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%
CHEMICALS	15,000	0.23	0.37%	0	0.00	0.00%	12,000	3.61	1.69%
MATERIALS & SUPPLIES	285,700	4.41	7.13%	4,300	0.39	1.06%	20,000	6.02	2.81%
CONTRACTED SERVICES	14,500	0.22	0.36%	0	0.00	0.00%	2,600	0.78	0.37%
TOTAL O&M	1,728,300	26.68	43.16%	117,200	10.67	29.01%	161,300	48.56	22.66%
COST CREDIT	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%
TOTAL COST	$4,004,300	$61.81	100.00%	$404,300	$36.77	100.00%	$711,900	$214.33	100.00%

1 dry ton = 0.9072 dry tonnes

All costs based on average loading condition:

Metro	177.5 tpd of dewatered sludge cake
Blackstone	30.1 tpd of dewatered sludge cake
Cranston	9.1 tpd of dewatered sludge cake

All costs based on unit costs developed in Section 4.

(1) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and gravity thickening of primary sludge.

(2) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and storage of thickened W.A.S. and primary sludge. (Note that the primary sludge holding tank acts as a gravity thickener.)

(3) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and gravity thickening of primary sludge.

TABLE E-6
COMPARISON OF ANNUAL SOLIDS HANDLING COSTS FOR SLUDGE DIGESTION AT CURRENT LOADING CONDITION
($/YEAR)

		DUFFIN (1)	
	ANNUAL COST	$/DT	% TOTAL $/DT
CAPITAL	$593,400	$60.44	80.73%
LABOR	54,100	5.50	7.35%
ELECTRICITY	65,400	6.66	8.90%
FUEL	0	0.00	0.00%
CHEMICALS	0	0.00	0.00%
MATERIALS & SUPPLIES	7,400	0.75	1.00%
CONTRACTED SERVICES	14,800	1.50	2.01%
TOTAL O&M	141,700	14.42	19.26%
TOTAL COST	$735,000	$74.85	100.00%

1 dry ton = 0.9072 dry tonnes

All costs based on unit costs developed in Section 4.

All costs based on average sludge production of 26.9 tpd of dewatered sludge cake.

(1) Includes sludge pumping from the clarifiers and sludge digestion.

TABLE 8-7
COMPARISON OF ANNUAL SOLIDS HANDLING COSTS
FOR CONDITIONING AND DEWATERING
AT CURRENT LOADING CONDITION
($/YEAR)

	METRO (1)			BLACKSTONE (2)			DUFFIN (3)			CRANSTON (4)		
	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT
CAPITAL	$ 5,717,000	$ 88.24	50.81%	$404,400	$36.81	47.53%	$ 525,000	$ 53.47	39.62%	$ 685,900	$ 206.50	62.94%
LABOR	3,334,700	51.47	29.63%	283,300	25.79	33.29%	388,800	39.60	29.34%	112,400	33.84	10.31%
ELECTRICITY	803,200	12.40	7.14%	57,400	5.22	6.75%	52,500	5.35	3.96%	51,500	15.51	4.73%
FUEL	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%
CHEMICALS	900,800	13.90	8.01%	79,800	7.26	9.38%	208,200	21.20	15.71%	185,900	55.97	17.06%
MATERIALS & SUPPLIES	462,400	7.14	4.11%	26,000	2.37	3.06%	117,900	12.01	8.90%	54,000	16.26	4.96%
CONTRACTED SERVICES	34,600	0.53	0.31%	0	0.00	0.00%	32,800	3.34	2.48%	0	0.00	0.00%
TOTAL O&M	5,535,700	85.44	49.19%	446,500	40.64	52.47%	800,200	81.50	60.38%	403,800	121.57	37.06%
COST CREDIT	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%
TOTAL COST	$11,252,700	$173.69	100.00%	$850,900	$77.45	100.00%	$1,325,200	$134.97	100.00%	$1,089,700	$328.07	100.00%

1 dry ton = 0.9072 dry tonnes

All costs based on average loading condition:

Metro	177.5 tpd of dewatered sludge cake
Blackstone	30.1 tpd of dewatered sludge cake
Duffin	26.9 tpd of dewatered sludge cake
Cranston	9.1 tpd of dewatered sludge cake

All costs based on unit costs developed in Section 4.

(1) Includes thermal sludge conditioning, roll press dewatering, and treatment of the thermal conditioning sidestream (RRC system).
(2) Includes polymier conditioning and belt filter press dewatering.
(3) Includes polymer conditioning and dewatering with diaphragm filter presses.
(4) Includes conditioning with lime and ferric and dewatering with diaphragm filter presses.

TABLE 8-8
COMPARISON OF ANNUAL SOLIDS HANDLING COSTS
FOR SLUDGE INCINERATION
AT CURRENT LOADING CONDITION
($/YEAR)

	METRO (1)			BLACKSTONE (2)			DUFFIN (3)			CRANSTON (4)		
	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT
CAPITAL	$10,913,400	$168.45	65.39%	$1,041,500	$94.80	64.06%	$2,052,800	$209.07	59.81%	$1,292,300	$389.07	70.73%
LABOR	4,125,400	63.68	24.72%	323,500	29.45	19.10%	498,300	50.75	14.52%	142,100	42.78	7.78%
ELECTRICITY	1,098,400	16.95	6.58%	150,400	13.69	9.25%	101,400	10.33	2.95%	83,900	25.26	4.59%
FUEL												
- Furnaces	273,400	4.22	1.64%	51,100	4.65	3.14%	63,400	6.46	1.85%	140,000	42.15	7.66%
- Aux Boilers	944,300	14.58	5.66%	—	—	—	206,600	21.04	6.02%	—	—	—
CHEMICALS	55,500	0.86	0.33%	0	0.00	0.00%	24,600	2.51	0.72%	0	0.00	0.00%
MATERIALS & SUPPLIES	709,200	10.95	4.25%	59,200	5.39	3.64%	447,400	45.57	13.03%	21,000	6.32	1.15%
CONTRACTED SERVICES	114,000	1.76	0.68%	0	0.00	0.00%	173,800	17.70	5.06%	147,800	44.50	8.09%
COST CREDIT	(1,543,200)	-23.82	-9.25%	0	0.00	0.00%	(135,900)	-13.84	-3.96%	0	0.00	0.00%
TOTAL O&M	5,776,900	89.17	34.61%	584,200	53.17	35.94%	1,379,600	140.51	40.19%	534,800	161.01	29.27%
TOTAL COST	$16,690,300	$257.62	100.00%	$1,625,700	$147.97	100.00%	$3,432,400	$349.58	100.00%	$1,827,100	$550.08	100.00%

1 dry ton = 0.9072 dry tonnes

All costs adjusted based on the unit costs developed in Section 4.

All costs based on average loading condition:

Metro	177.5 tpd of dewatered sludge cake
Blackstone	30.1 tpd of dewatered sludge cake
Duffin	26.9 tpd of dewatered sludge cake
Cranston	9.1 tpd of dewatered sludge cake

(1) Includes incineration, heat recovery, ash disposal, and auxiliary boiler systems.

(2) Includes incineration and ash disposal systems.

(3) Includes incineration, heat recovery, ash disposal, and auxiliary boiler systems.

(4) Includes incineration, heat recovery, and ash disposal systems.

APPENDIX F
SUMMARY OF OPERATION AND MAINTENANCE COSTS AT CAPACITY LOADING

TABLE F-1
METRO WPCP
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT SYSTEM CAPACITY
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS & SUPPLIES	CONTRACTED SERVICES	TOTAL O&M COST	COST CREDIT	NET O&M COST	% TOTAL NET COST	NET $/DRY TON
Sludge Pumping[1]	$ 0	$ 176,500	$ 0	$ 0	$ 0	$ 0	$ 176,500	$ 0	$ 176,500	1.09%	$ 2.01
W.A.S. Thickening	684,000	405,200	0	0	320,600	4,700	1,414,600	0	1,414,600	8.70	16.15
Primary Sludge Thickening	414,300	51,500	0	20,200	60,400	14,700	561,100	0	561,100	3.45	6.41
Sludge Storage Tanks	626,200	171,800	0	28,500	49,500	700	876,700	0	876,700	5.39	10.01
Thermal Conditioning	1,669,400	462,200	0	34,000	359,000	26,000	2,550,600	0	2,550,600	15.69	29.12
Sludge Dewatering	1,837,700	261,600	0	1,023,600	114,000	6,400	3,243,300	0	3,243,300	19.94	37.02
Sludge Incineration[2]	4,310,700	861,300	364,600	0	797,100	149,100	6,482,800	0	6,482,800	39.85	74.00
Boiler System	892,400	272,100	629,800	75,300	136,300	9,600	2,015,500	1,543,200	472,300	2.90	5.40
RDC System	197,100	123,300	0	69,000	88,100	11,800	489,300	0	489,300	3.01	5.59
TOTAL	$10,631,800	$2,785,600	$994,600	$1,250,600	$1,944,900	$223,000	$17,830,300	$1,543,200	$16,287,100	100.00%	185.93

1 dry ton = 0.9072 dry tonne

[1] This line item includes pumping from the primary and secondary clarifiers to the sludge thickening process.

[2] Includes ash disposal costs.

All costs adjusted based on system capacity of 240 dry tpd of dewatered cake.
All subsequent sludge pumping is included in the appropriate unit process line item.
All costs reflect operation at estimated system capacity of 240 dry tpd of dewatered cake.

TABLE F-2

UPPER BLACKSTONE WPCF
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT SYSTEM CAPACITY
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS	TOTAL O&M COST	% TOTAL O&M COST	O&M COST $/DRY TON
Sludge Pumping	$ 78,000	$ 20,800	$ 0	$ 0	$ 2,000	$ 100,800	4.89%	$ 4.60
W.A.S. Thickening	20,000	68,800	0	0	6,600	95,400	4.63	4.36
Holding Tanks	6,000	100	0	0	0	6,100	0.30	0.28
Blending/Dewatering	432,500	62,800	0	159,000	51,800	706,100	34.25	32.24
Sludge Incineration	588,700	231,400	102,100	0	106,600	1,028,800	49.91	46.98
Ash Disposal	56,200	0	0	0	11,800	68,000	3.30	3.07
TOTAL	$1,181,400	$383,900	$102,100	$159,000	$178,800	$2,005,200	100.00%	$91.53

1 dry ton = 0.9072 dry tonnes

All costs reflect operation at estimated system capacity of 60 dry tons per day of dewatered cake.

All costs adjusted based on the unit costs developed in Section 4.

TABLE F-3

DUFFIN CREEK WPCP
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT SYSTEM CAPACITY
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS	PURCHASED SERVICES	TOTAL O&M COST	COST CREDIT	NET O&M COST	% TOTAL NET COST	NET $/DRY TON
Sludge Pumping	$ 0	$ 1,700	$ 0	$ 0	$ 0	$ 0	$ 1,700	$ 0	$ 1,700	0.10%	$ 0.16
Sludge Digestion	55,200	65,500	0	0	8,200	16,400	145,300	0	145,300	7.89	13.27
Sludge Dewatering	432,000	54,100	0	230,600	117,900	36,400	871,000	0	871,000	47.31	79.54
SUBTOTAL[1]	$487,200	$121,300	$ 0	$230,600	$126,100	$ 52,800	$1,018,000	$ 0	$1,018,000	55.30%	$ 93
Sludge Incineration	$615,600	$137,300	$151,300	$ 54,700	$420,800	$65,600	$1,445,300	$135,800	$1,309,500	35.57	59.79
Ash Disposal	36,500	0	0	0	59,200	240,400	336,100	0	336,100	9.13	15.35
SUBTOTAL[2]	$652,100	$137,300	$151,300	$54,700	$480,000	$306,000	$1,781,400	$135,800	$1,645,600	44.70%	$75
TOTAL										100%	$168

1 dry ton = 0.9072 dry tonnes

NOTE: All costs presented in U.S. dollars and based on September 1988 cost index.
All costs adjusted based on the unit costs developed in Section 4.

[1] Reflects operation at estimated digestion/dewatering system capacity of 30 dry tpd of dewatered cake.

[2] Relfects operation at estimated incineration system capacity of 60 dry tpd of dewatered cake.
$/dry ton = $1.10/dry tonne

TABLE F-4

CRANSTON WPCF
O&M COSTS FOR SOLIDS HANDLING PROCESSES
AT SYSTEM CAPACITY
($/YEAR)

PROCESS	LABOR	ELECTRICITY	FUEL	CHEMICALS	MATERIALS & SUPPLIES	CONTRACTED SERVICES	TOTAL O&M COST	% TOTAL O&M COST	O&M COST $/DRY TON
Sludge Pumping	$ 0	$ 1,200	$ 0	$ 0	$ 0	$ 0	$ 1,200	0.06%	$ 0.11
W.A.S. Thickening	141,700	24,700	0	39,600	40,000	0	246,000	12.35	22.47
Primary Sludge Thickening	136,500	16,500	0	0	0	2,600	155,600	7.81	14.21
Sludge Blending Tanks	42,300	1,400	0	4,300	24,000	0	72,000	3.62	6.58
Sludge Dewatering	168,800	72,800	0	598,700	60,000	0	900,300	45.21	82.22
Sludge Incineration	168,800	83,900	82,100	0	11,000	127,800	473,600	23.78	43.25
Ash Disposal	43,800	0	0	0	33,000	65,900	142,700	7.17	13.03
TOTAL	$701,900	$200,500	82,100	$642,600	$168,000	$196,300	$1,991,400	100.00%	$182

1 dry ton = 0.9072 dry tonne

All costs adjusted based on the unit costs developed in Section 4.
All capital reflect operation at estimated system capacity of 30 dry tons per day of dewatered cake.

$/dry ton = $1.10/dry tonne

TABLE F-5

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS
FOR SLUDGE THICKENING
AT SYSTEM CAPACITY
($/YEAR)

	METRO (1)			UPPER BLACKSTONE (2)			CRANSTON (3)		
	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT	ANNUAL COST	$/DT	% TOTAL $/DT
CAPITAL	$2,276,000	$25.98	$51.40	$286,800	$13.10	$58.64	$550,600	$50.28	57.75%
LABOR	1,098,300	12.54	24.80	104,000	4.75	21.26	278,200	25.41	29.18%
ELECTRICITY	633,300	7.23	14.30	89,700	4.10	18.34	42,400	3.87	4.45%
FUEL	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%
CHEMICALS	20,200	0.23	0.46	0	0.00	0.00	39,600	3.62	4.15%
MATERIALS & SUPPLIES	381,000	4.35	8.60	8,600	0.39	1.76	40,000	3.65	4.20%
CONTRACTED SERVICES	19,400	0.22	0.44	0	0.00	0.00	2,600	0.24	0.27%
TOTAL O&M	2,152,200	24.57	48.60	202,300	9.24	41.36	402,800	36.79	42.25%
TOTAL COST	$4,428,200	$50.55	100.00%	$489,100	$22.34	100.00%	$953,400	$87.07	100.00%

1 dry ton = 0.9072 dry tonne

All costs are based on operation at system capacity.

All costs adjusted based on the unit costs developed in Section 4.

The solids train capacity for each facility is estimated as follows:

Metro	240 tpd of dewatered cake
Blackstone	60 tpd of dewatered cake
Cranston	30 tpd of dewatered cake

(1) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and gravity thickening of primary sludge.

(2) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and storage of thickened W.A.S. and primary sludge. (Note that the primary sludge holding tank acts as a gravity thickener.)

(3) Includes sludge pumping from the clarifiers, flotation thickening of W.A.S., and gravity thickening of primary sludge.

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TABLE F-6

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS FOR DUFFIN CREEK SLUDGE DIGESTION AT SYSTEM CAPACITY ($/YEAR)

	DUFFIN (1)		
	ANNUAL COST	$/DT	% TOTAL $/DT
CAPITAL*	$593,400	$54.19	80.15%
LABOR	55,200	5.04	7.45%
ELECTRICITY	67,200	6.14	9.08%
FUEL	0	0.00	0.00%
CHEMICALS	0	0.00	0.00%
MATERIALS & SUPPLIES	8,200	0.75	1.11%
CONTRACTED SERVICES	16,400	1.50	2.22%
TOTAL O&M**	147,000	13.42	19,85%
TOTAL COST	$740,400	$67.62	100.00%

1 dry ton = 0.9072 dry tonne

(1) Includes sludge pumping from the clarifiers and sludge digestion.

All costs are based on operation at the estimated system capacity of 30 dry tpd of dewatered cake.

$/dry ton = $1.10/dry tonne

TABLE F-7

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS
FOR CONDITIONING AND DEWATERING
AT SYSTEM CAPACITY
($/YEAR)

	METRO (1)			BLACKSTONE (2)			DUFFIN (3)			CRANSTON (4)		
	ANNUAL COST	$/DT	% TOTAL	ANNUAL COST	$/DT	% TOTAL	ANNUAL COST	$/DT	% TOTAL	ANNUAL COST	$/DT	% TOTAL
CAPITAL	$ 5,717,000	$ 65.26	44.40%	$404,400	$18.47	36.42%	$ 525,000	$47.95	37.61%	$ 685,900	$ 62.64	41.36%
LABOR	4,330,400	49.43	33.63%	432,500	19.75	38.95%	432,000	39.45	30.95%	211,100	19.28	12.73%
ELECTRICITY	1,018,800	11.63	7.91%	62,800	2.87	5.66%	54,100	4.94	3.88%	74,200	6.78	4.47 %
FUEL	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%	0	0.00	0.00%
CHEMICALS	1,018,800	13.19	8.97%	159,600	7.26	14.32%	230,600	21.06	16.52%	603,000	55.07	36.36%
MATERIALS & SUPPLIES	610,600	6.97	4.74%	51,800	2.37	4.66%	117,900	10.77	8.45%	84,000	7.67	5.07 %
CONTRACTED SERVICES	44,900	0.51	0.35%	0	0.00	0.00 %	36,400	3.32	2.61%	0	0.00	0.00 %
TOTAL O&M	7,159,800	81.73	55.60	706,100	32.24	63.58	871,000	79.54	62.39	972,300	88.79	58.64%
TOTAL COST	$12,876,800	$147.00	100.00%	$1,110,500	$50.71	100.00%	$1,396,000	$127.49	100.00%	$1,658,200	$151.43	100.00%

1 dry ton = 0.9072 dry tonne

All costs adjusted based on the unit costs developed in Section 4.
All costs are based on operation at system capacity.

The solids train capacity for each facility is estimated as follows:
Metro 240 tpd of dewatered cake
Blackstone 60 tpd of dewatered cake
Duffin 30 tpd of dewatered cake
Cranston 30 tpd of dewatered cake

(1) Includes thermal sludge conditioning, roll press dewatering, and treatment of the thermal conditioning sidestream (RBC system).
(2) Includes polymer conditioning and belt filter press dewatering.
(3) Includes polymer conditioning and dewatering with diaphragm filter presses.
(4) Includes conditioning with lime and ferric and dewatering with diaphragm filter presses.

TABLE F-4

COMPARISON OF ANNUAL SOLIDS HANDLING COSTS

SLUDGE INCINERATION

($/YEAR)

	METRO (1)			UPPER BLACKSTONE (2)			DUFFIN (3)			CRANSTON (4)		
	ANNUAL COST	$/DT	% TOTAL	ANNUAL COST	$/DT	% TOTAL	ANNUAL COST	$/DT	% TOTAL	ANNUAL COST	$/DT	% TOTAL
CAPITAL*	$10,913,400	$124.58	61.08%	$1,041,500	$47.56	48.71%	$2,052,000	$ 93.74	55.51%	$1,292,300	$118.02	67.71%
LABOR	5,203,100	59.40	29.12%	644,900	29.45	30.16%	652,100	29.78	17.63%	212,600	19.42	11.14%
ELECTRICITY	1,133,400	12.94	6.34 %	231,400	10.57	10.81%	137,300	6.27	3.71 %	83,900	7.66	4.40%
FUEL												
- Furnaces	364,600	4.16	2.04 %	102,100	4.65	4.77 %	141,500	6.46	3.83%	82,100	7.50	4.30%
- Aux Boilers	629,800	7.19	3.52 %	—	—	—	9,800	0.45	0.26%	—	—	—
CHEMICALS	75,300	0.86	0.42 %	0	0.00	0.00 %	54,700	2.50	1.48%	0	0.00	0.00 %
MATERIALS & SUPPLIES	933,400	10.66	5.22 %	118,400	5.39	5.53 %	480,000	21.92	12.98%	44,000	4.02	2.31%
CONTRACTED SERVICES	158,700	1.81	0.89 %	0	0.00	0.00 %	306,000	13.97	8.27%	193,700	17.69	10.15%
COST CREDIT	(1,543,200)	-17.62	-8.63%	0	0.00	0.00%	(135,900)	-6.20	-3.67%	0	0.00	0.00%
TOTAL O&M**	6,955,100	79.40	38.92	1,096,800	50.05	51.29	1,645,600	75.14	44.49	616,300	56.28	32.29
TOTAL COST	$17,868,500	$203.98	100.00%	$2,138,300	$97.61	100.00%	$3,698,400	$168.88	100.00%	$1,908,600	174.30	100.00%

1 dry ton = 0.9072 dry tonne

All costs adjusted based on the unit costs developed in Section 4.

All costs are based on operation at system capacity.

The incineration system capacity for each facility is estimated as follows:

Metro	240 tpd of dewatered cake
Blackstone	60 tpd of dewatered cake
Duffin	60 tpd of dewatered cake
Cranston	30 tpd of dewatered cake

(1) Includes incineration, heat recovery, ash disposal, and auxiliary boiler systems.

(2) Includes incineration and ash disposal systems.

(3) Includes incineration, heat recovery, ash disposal, and auxiliary boiler systems.

(4) Includes incineration, heat recovery, and ash disposal systems.

APPENDIX G
CAPITAL COST
SUMMARY TABLES

TABLE G-1

METRO WPCF
CONSTRUCTION COSTS

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4535)	AMORTIZED CAPITAL COST*
W.A.S. Thickening		
- structures	$ 15,828,400	$ 1,327,300
- equipment	$ 4,150,500	$ 422,700
- total	$ 19,978,900	$ 1,750,000
Primary Sludge Thickening		
- structures	$ 5,400,000	$ 452,900
- equipment	$ 500,000	$ 51,000
- additional structure**	$ 235,500	$ 19,800
- additional equipment**	$ 21,800	$ 2,300
- total	$ 5,900,000	$ 526,000
Thermal Conditioning		
- structures	$ 26,400,000	$ 2,213,700
- equipment	$ 10,972,000	$ 1,117,300
- total	$ 37,372,000	$ 3,331,000
Sludge Dewatering***		
- structures	$ 778,400	$ 65,100
- equipment	$ 3,994,900	$ 406,900
- total	$ 4,773,300	$ 472,000
Sludge Incineration		
- structures	$ 92,759,900	$ 7,778,800
- equipment	$ 30,776,300	$ 3,134,600
- total	$123,536,200	$10,913,400
RBC Sidestream Treatment		
- structures	$17,380,100	$ 1,457,600
- equipment	$4,481,500	$ 456,400
- total	$21,861,600	$ 1,914,000

*Based upon a discount rate of 8%. Assumes all structures will have a useful life of 40 years and all equipment will have a useful life of 20 years.

**Additional gravity thickener.

***Based on roll press dewatering capital costs.

TABLE G-2

UPPER BLACKSTONE WPCF
CONSTRUCTION COSTS

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4535)	AMORTIZED CAPITAL COST*
Waste Activated Sludge Thickening		
- structures	$1,737,200	$145,700
- equipment	$ 681,100	$ 69,400
- total	$2,418,300	$215,100
Sludge Holding Tanks		
- structures	$683,400	$57,300
- equipment	$140,900	$14,400
- total	$824,300	$71,700
Sludge Dewatering		
- structures	$2,460,800	$206,400
- equipment	$1,644,000	$167,400
- additional equipment**	$ 300,000	$ 30,600
- total	$4,404,800	$404,400
Sludge Incineration		
- structures	$ 3,623,700	$ 303,900
- equipment	$ 7,242,500	$ 737,600
- total	$10,866,200	$1,041,500

*Based upon a discount rate of 8%. Assumes all structures will have a useful life of 40 years and all equipment will have a useful life of 20 years.

**Additional belt filter press.

TABLE G-3

DUFFIN CREEK WPCF
CONSTRUCTION COSTS
(U.S. DOLLARS)

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4535)	AMORTIZED CAPITAL COST*
Sludge Digestion		
- structures	$4,235,000	$355,100
- equipment	$2,340,000	$238,300
- total	$6,575,000	$593,400
Sludge Conditioning/Dewatering		
- structures**	$3,824,000	$320,700
- equipment	$2,006,000	$204,300
- total	$5,830,000	$525,000
Sludge Incineration		
- structures	$13,341,000	$1,118,800
- equipment	$ 9,170,000	$ 934,000
- total	$22,511,000	$2,052,800

*Based upon a discount rate of 8%. Assumes all structures will have a useful life of 40 years and all equipment will have a useful life of 20 years.

**Adjusted to correct for excessive building volume.

TABLE G-4

CRANSTON WPCF CONSTRUCTION COSTS

PROCESS	UPDATED CONSTRUCTION COST (ENR = 4535)	AMORTIZED CAPITAL COST*
Sludge Thickening		
- structures	$2,700,000	$226,400
- equipment	$3,100,000	$315,700
- additional structures**	$ 90,000	$ 7,500
- additional equipment**	$ 10,000	$ 1,000
- total	$5,900,000	$550,600
Sludge Dewatering		
- structures	$4,900,000	$410,900
- equipment	$2,700,000	$275,000
- total	$7,600,000	$685,900
Sludge Incineration		
- structures	$ 2,900,000	$ 243,200
- equipment	$10,300,000	$1,049,100
- total	$13,200,000	$1,292,300

*Based upon a discount rate of 8%. Assumes all structures will have a useful life of 40 years and all equipment will have a useful life of 20 years.

**Additional gravity thickener.